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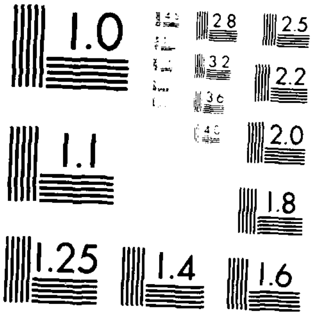
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Volume 2

OVERGROUND EXCESS SOUND ATTENUATION (ESA)

VOLUME 2. ANALYSIS OF DATA FOR FLAT GRASSY TERRAIN CONDITIONS

DWIGHT E. BISHOP

BOLT BERANEK AND NEWMAN INC.
21120 VANOWEN ST.
CANOGA PARK, CALIFORNIA 91303

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Henning E. von Gierke

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Director
Biodynamics and Bioengineering Division
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This is one report of a series concerning overground excess sound attenuation, ESA. Analysis of the ESA data acquired under the Air Force measurements at Wright-Patterson AF Base show the expected large variations with weather and ground surface conditions for flat grassy terrain. Multiple linear regression analyses show low to moderately high correlations of excess attenuation data with the wind component in the direction of sound propagation, the temperature gradient and the ground surface (grass or snow). A characteristic of the data is the maximum excess attenuation typically occurring between 160 and 250 Hz which is related to the ground impedance. This maximum is evident in all data except under large negative wind component and negative temperature gradient conditions. Theoretical calculations show a reasonable fit of the ESA data for surface flow resistivity values of 100 to 200 cgs units for grass and 20 to 50 cgs units for snow. The extent of changes in ESA values with changes in wind component or temperature gradient varies considerably with frequency and distance. At low frequencies,

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typically 25 to 100 Hz, attenuation values generally show well-ordered increases with decreasing wind component and temperature gradient values. At frequencies above about 300 Hz, ESA sensitivity to wind component and temperature gradient increases, with generally a greater range of change occurring for negative values of wind component and temperature gradient than for positive values.

The trends in the data are consistent with those shown in the earlier work of Parkin and Scholes in Great Britain. Comparison of the ESA values for near zero wind component and neutral temperature conditions with theoretical models shows general good fit if one allows for a moderate increase in the flow resistivity with distance. Introduction of turbulent atmosphere adjustments greatly improves the fit between experiment and model calculations for distances beyond about 500 meters.

The current data show major differences compared to the ESA values now used in NOISEMAP. One reasons for some of the observed differences is that the present NOISEMAP values are based on field airport/community measurements where, unlike the current measurements, there were many intervening objects between the airplane source and distant measuring positions.

AFAMRL-TR-84-017, Volumes 1 and 3 of this series concern the experimental study and all measured data, and application of ESA data to Air Force noise prediction programs.

PREFACE

This research was performed for the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio, under Project/Task 723107, Technology to Define and Assess Environmental Quality of Noise From Air Force Operations. Administration and technical monitors for this effort were Mr. Jerry D. Speakman and Mr. Robert G. Powell, respectively, both of the Biodynamic Environmental Branch, Biodynamics and Bioengineering Division.

This study analyzes noise and meteorological data from the same Project/Task and Organization as listed above. The author gratefully acknowledges the guidance and helpful information provided by Mr. Robert Powell of the Biodynamic Environmental Branch, and the assistance of Henry T. Mohlman, University of Dayton, in accessing the data acquired in the Air Force measurement program. Also acknowledged are the major contributions of Ms. Emma Wilby, BBN, who handled the statistical analyses utilizing the BMD statistical program package, and who prepared and exercised the analytical model computer programs.

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ANALYSIS OF OVERGROUND EXCESS SOUND ATTENUATION

1.0 INTRODUCTION

This report describes and analyzes the results of an extensive set of field noise measurements undertaken to determine the sound attenuation for horizontal propagation of sound from jet engine ground runups. The measurements were undertaken for the purposes of obtaining improved understanding of the attenuation of sound occurring under real life conditions and, in particular, of obtaining information for developing improved methods for predicting ground runup noise for the NOISEMAP airport noise modeling computer program.

The noise sources were jet engines installed in C-135 and C-141 aircraft. During aircraft runups at high power, noise and meteorological data were collected at various positions that ranged in distance from 66 meters (216 feet) to 2377 meters (7800 feet) from the engines. Some 421 sets of measurements were collected during daytime hours over a 15-month period (November 1979 to February 1981). All of the measurements were made at Wright-Patterson AFB over near-level terrain which was grass or snow-covered.

This study examines the differences in noise levels observed at different positions after measured noise levels have been adjusted for inverse square propagation and air absorption. These differences are termed excess sound attenuation (ESA). The ESA measurements show considerable variability.

Much of the analysis in this report will be concerned with relating the variability in ESA values with various physical parameters and with comparing measurement results with other field studies and with predictions of theoretical models.

The field measurements and the data collection and processing are described in detail separately and hence will not be presented in this report (Reference 1). Application of these data to improve prediction procedures of noise from USAF aircraft ground runups is published in another report (Reference 2).

Section 2 of the report briefly describes the measurements, presents an overview of the range of meteorological conditions and excess attenuation values observed and describes both the noise source and excess sound attenuation variability as a function of frequency and distance. Section 3 describes the results of multiple linear regression analyses undertaken to determine the correlation of the excess attenuation values with various meteorological, ground surface and test variables. Section 4 compares the average ESA values observed for different wind component and temperature gradient conditions and for two ground surface conditions (grass and snow-covered).

Section 5 compares the experimental results with the field measurements of Parkin and Scholes (References 3, 4 and 5) and Franken and Bishop (Reference 8), and with theory. A summary, conclusions and recommendations complete the body of the report.

2.0 OVERVIEW OF TEST PROGRAM AND TEST DATA

2.1 General Test Description

The noise sources were jet engines installed in C-135A aircraft (powered with J57 turbojet engines) and C-135B and C-141 aircraft (powered with TF-33 turbofan engines). Most of the runs (413 of the 421) were made with the C-135A aircraft. The centerlines of the C-135's were 1.5 m (5 feet) above the ground and 2.4 m (8 feet) for the C-141.

The measurements were made in opposing directions along a line parallel to one of the air base taxiways. Figure 1 shows the elevation profile and plan view of the two microphone arrays, and the approximate orientation of the aircraft with respect to the arrays. At all but the closest position (the reference position) the measuring microphones were located 1.5 m (5 feet) above the ground. At the reference position, located either 66 or 75 m (217 or 246 feet) from the source, noise events were measured with two microphones located 0.3 and 2.4 m (1 and 8 feet) above the ground. Output from the two microphones were later summed on the energy basis to establish the reference level. For 10 events, a scanning microphone which moved between heights of 0.3 and 3 m (1 and 10 feet above the ground) was used. And for six events, the output from microphones at the farther distances of 134 and 238 m (440 and 781 feet) were used as the reference levels.

For the runs, pilots were instructed to use maximum takeoff power. In doing so the pilots would choose an EPR (engine pressure ratio) for weather conditions at the start of a testing period, usually one to two hours long. During some of the periods the weather would change enough so that the EPR settings could no longer be achieved and therefore, had to be lowered to match current weather conditions.

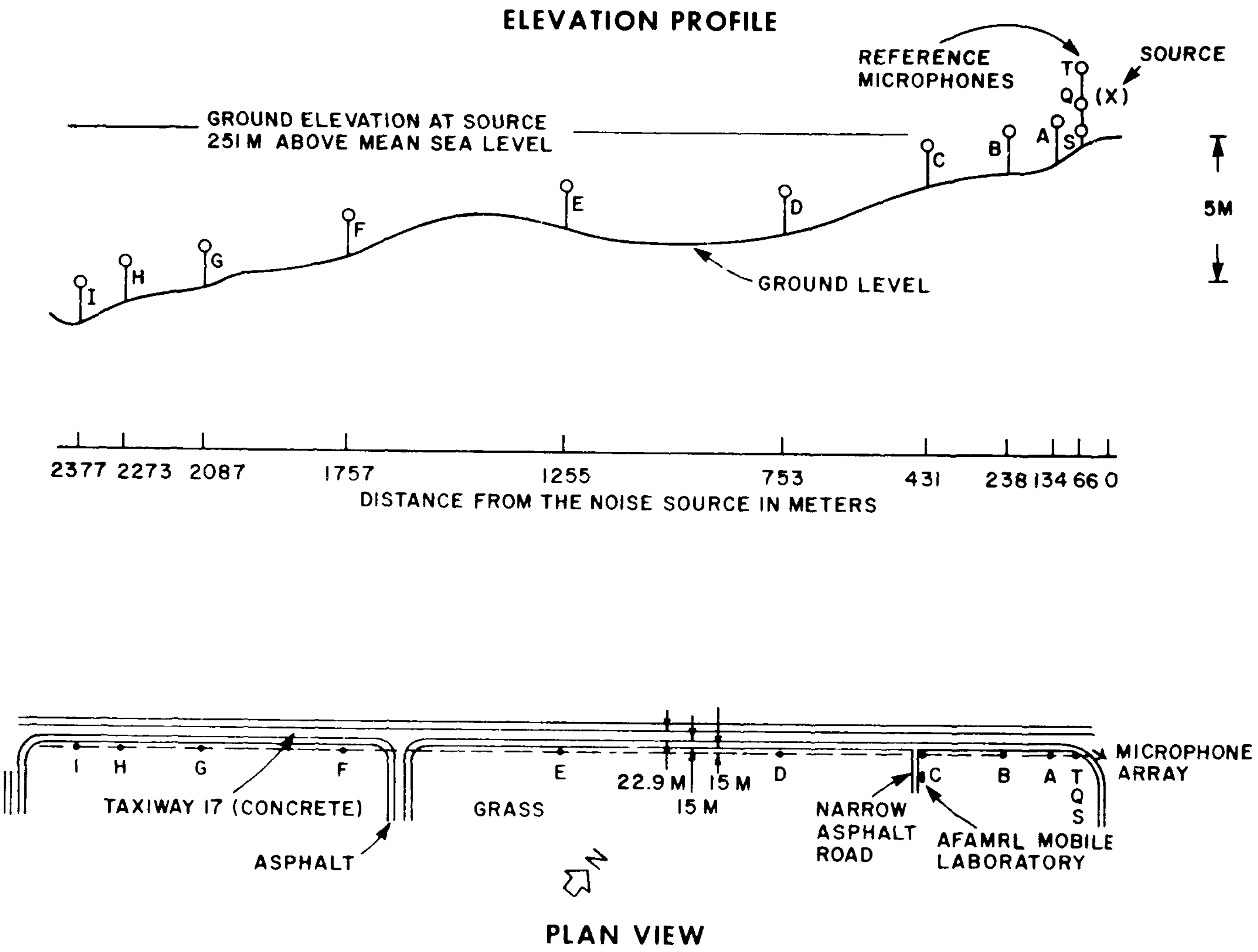
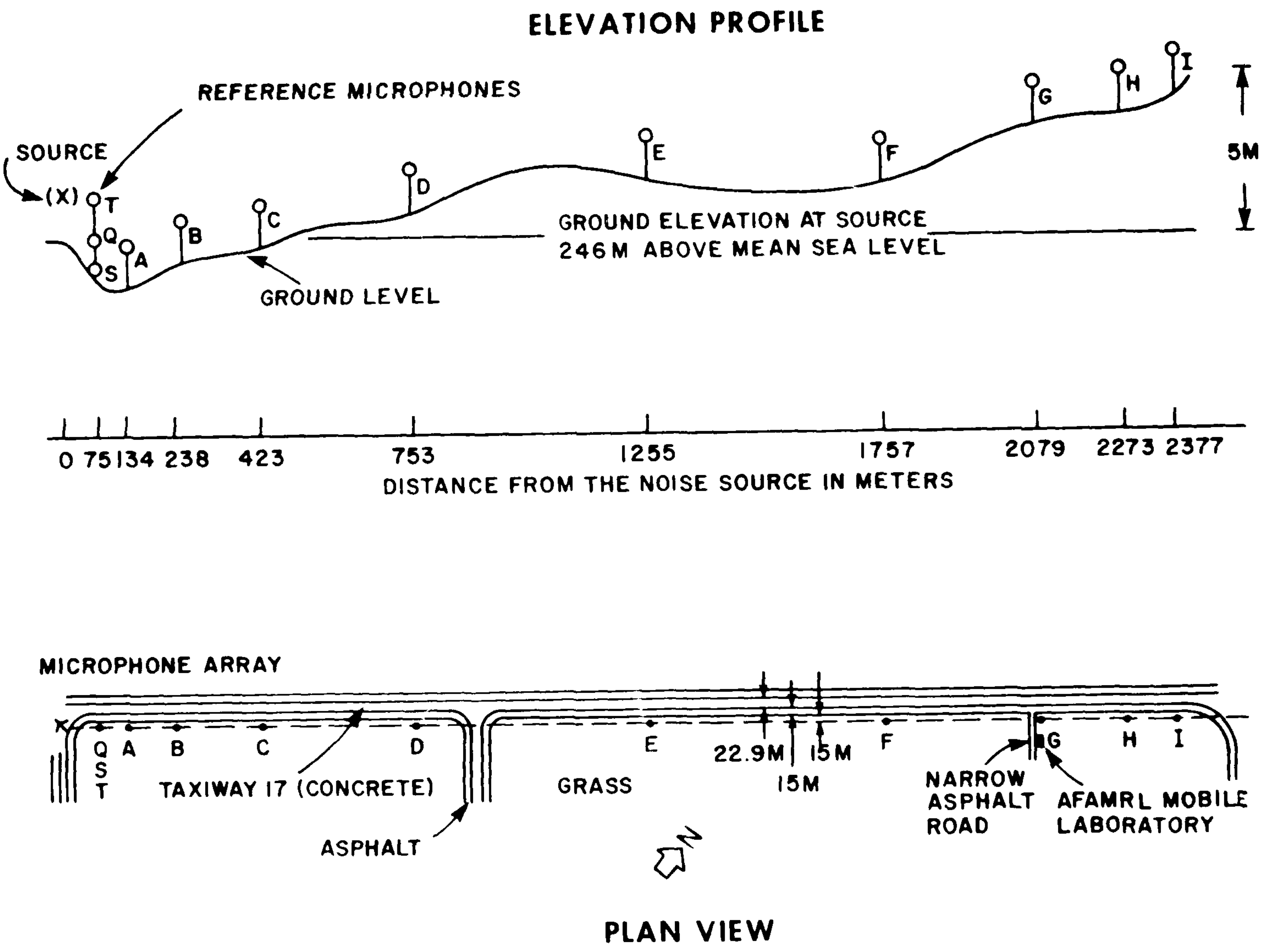

ELEVATION PROFILE
REFERENCE MICROPHONES
SOURCE
T
Q
(X)
A
S
B
C
D
E
F
G
H
I
GROUND ELEVATION AT SOURCE
251 M ABOVE MEAN SEA LEVEL
GROUND LEVEL
5M
2377
2273
2087
1757
1255
753
431
238
134
66
0
DISTANCE FROM THE NOISE SOURCE IN METERS
MICROPHONE ARRAY
I
H
G
F
E
22.9 M
15 M
15 M
D
C
B
A
T
Q
S
TAXIWAY 17 (CONCRETE)
ASPHALT
GRASS
N
NARROW ASPHALT ROAD
AFAMRL MOBILE LABORATORY
PLAN VIEW

FIGURE 1 A. TEST ARRAY PROFILE AND PLAN VIEW ARRAY 03


ELEVATION PROFILE
REFERENCE MICROPHONES
SOURCE
(X)
T
Q
S
A
B
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D
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F
G
H
I
5M
GROUND ELEVATION AT SOURCE
246M ABOVE MEAN SEA LEVEL
GROUND LEVEL
0 75 134 238 423 753 1255 1757 2079 2273 2377
DISTANCE FROM THE NOISE SOURCE IN METERS
MICROPHONE ARRAY
X
Q A B C D
S
T
TAXIWAY 17 (CONCRETE)
ASPHALT
E
GRASS
22.9M
15M
15M
F
NARROW
ASPHALT
ROAD
G H I
AFAMRL MOBILE
LABORATORY
N
PLAN VIEW

FIGURE 1 B. TEST ARRAY PROFILE AND PLAN VIEW ARRAY 04

Noise was measured at nine distances from the source ranging from the reference positions out to a distance of 2377 m (7800 ft) on some runs. Table 1 lists the different measurement positions that were used.* Data were not necessarily obtained at all of these positions for each measurement event.

The noise was measured at each position for durations of at least 30 seconds. Noise levels were sampled at half second intervals and the energy average computed over the run time. Times for averaging were adjusted to account for finite sound propagation time between positions.

The noise data was analyzed in one-third octave frequency bands, at center frequencies extending from 25 to 10,000 Hz. Overall and A-levels were also determined.

Field temperatures were measured at three heights, 0.3, [illegible] and 9.2 meters above ground at one position. Wind was measured at approximately 2 meters above ground at two positions along the traverse.

2.2 Calculation of Excess Sound Attenuation Values

For this report, the excess sound attenuation (ESA) values were determined as follows:

1. The average noise levels at each position (other than the reference position) were increased by the amount of inverse square and air absorption losses occurring between the reference microphone and the position. Air absorption losses were based on the field temperature and relative humidity for the run, using the tables of ARP 866A (Reference 6).

---

*Throughout the report, distances refer to the distance between source and measurement position.

TABLE 1. MEASUREMENT POSITIONS

Position	Distance from Source	
	Meters	Feet
S*	66 or 75	217 or 246
A	134	440
B	238	781
C	431	1414
D	753	2471
E	1255	4118
F	1757	5765
G	2087	6847
H	2273	7458
I	2377	7800

*Reference microphone position.

2. These adjusted levels for each position were then subtracted from the average levels at the reference position. The differences were tabulated for each position (other than the reference position) and defined as the excess sound attenuation for the particular run.

As explained in Volume 1 (Reference 1), the reason this method is used is tied to the ESA application to the USAF aircraft noise data base for ground runups. The method results in ESA values that represent the excess sound attenuation occurring for propagation between the reference position and more distant positions. These ESA values may not represent the total excess sound attenuation between the engine source and the specified position, since there may be additional excess attenuation between the source and the reference position. Although this additional excess attenuation is not applicable to USAF noise prediction models (since the models, Reference 1, already contain this additional attenuation) it is discussed in Section 5 for a more complete analysis of ESA.

Excess attenuation values were also computed for the overall sound pressure level and A-weighted sound level. For the reference position, the measured average overall and A-levels were determined. At other positions, the average overall and A-levels were computed from the average spectra after the spectra were adjusted for inverse square radiation and air absorption (see Step 1, above). These computed overall and A-levels were then compared to the average measured overall and A-levels at the reference position.

Note that the removal of air absorption losses in computing the overall and A-levels at other than the reference position changes the spectrum shape (increases the relative levels at the higher frequencies) over what would be observed in the field. The general effect of this procedure is to yield ESA values for the overall and A-level that are smaller than would typically be observed in the field.

2.3 Data Handling and Data Analysis Programs

Two special digital computer programs were developed for use in ESA analyses. These unpublished programs are discussed in Reference 1. The first of these programs, Omega 12, calculates the average ESA values for each ground runup along with averaged weather conditions. The other program, Omega 13, provides a means to parametrically sort data and provide a summary across all runup data.

General data sorting, averaging, plotting of histograms and fitting of regression lines and the multiple linear regression analyses were undertaken by using various of the BMDP computer programs (Reference 7). In addition, special computer programs were written to calculate excess sound attenuation based on analytic models, as described in Appendix A.

2.4 Meteorological and Ground Conditions

Table 2 summarizes the distribution of temperature, windspeed and wind component conditions during the tests. Maximum and minimum values as well as the 10%, 25%, 50%, 75% and 90% values are listed.

The temperature range extended from -16.5 to 33°C with 50% of the measurements made in the temperature range between -1 to 14.5°C. Most of the wind measurements were made at low speeds with 50% of the measurements for windspeeds of 1.9 meters per

TABLE 2. DISTRIBUTION OF BASIC METEOROLOGICAL CONDITIONS

	[illegible]						
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	−	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

second (4.3 mph) or less. The magnitude of the wind component in the direction of sound propagation was generally small, with 50% of the measurements made with the wind components ranging from -1 to +1 meter per second (±2.2 mph).

The temperature gradient was described in terms of alpha* defined as:

$$\alpha = 0.607 \frac{T_1 - T_3}{\ln \frac{h_1}{h_3}} \qquad \text{(m/sec.)}$$

where

T_1 = temperature (°C) at 9.2 m above ground
T_3 = temperature (°C) at 0.3 m above ground
h_1 = height of 9.2 m above ground
h_3 = height of 0.3 m above ground

For a standard atmosphere lapse rate, alpha is -0.175 m/sec.

The measured alpha values range from -0.9 to +0.74 m/sec. with 50% of the measurements ranging from -0.22 to +-.07 m/sec.

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*More rigorously, alpha is the sound velocity gradient in the vertical direction, z. Thus:

$$\alpha = \frac{dc}{dz} = \frac{\partial c}{\partial T} \cdot \frac{\partial T}{\partial z} \approx a\,(0.607) \qquad \text{(m/sec.)}$$

where $$a = \frac{\partial T}{\partial z} \approx \frac{T_1 - T_3}{\ln \frac{h_1}{h_3}} \qquad \text{(°C)}$$

c = velocity of sound, m/sec.

Approximately 92% of the measurements were taken without any precipitation and the remaining 8% were made with light rain or snow falling. The ground surface was either hard packed or frozen (hard packed 86.5% of the time or frozen, 13.5% of the time). The ground surface conditions varied as shown in Table 3. You will note a distribution of ground surface conditions ranging from dry through wet, frost and snow covered conditions.

Measurements were made in the daytime between the hours of 6 am and 4 pm. Sixty-three percent of the measurements were made between 6 and 11 am. Most frequently, measurements were made between 7 and 8 am or 1 and 2 pm, coinciding with aircraft flight schedules.

The joint distributions of some meteorological parameters are of interest. Of particular interest is the distribution of temperature and relative humidities since these quantities largely determine the air absorption. Figure 2 shows a scatter plot of relative humidity versus temperature. Also shown on the scatter plot are lines of equal air absorption for a one-third octave frequency band centered at 1000 Hz.*

Figure 3 shows the distribution of alpha versus the wind component in the direction of sound propagation. This is of interest because of the correlations of ESA with alpha and the wind component as discussed later.

Some trends with time of day may be of interest. There was a relatively strong correlation of decreasing alpha values with time of day ($r^2 = 0.55$) as shown in Figure 4 indicating a strong trend toward negative temperature gradients as time progressed.

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*These are based on the SAE ARP 866A tables of Reference 6.

TABLE 3. STATUS OF GROUND COVER DURING MEASUREMENTS

Ground Cover Condition	Percent of Measurements
Dry	23.0
Wet ground and grass	14.5
Wet ground, dry grass	1.2
Dew, dry ground	33.3
Frost	3.8
Snow, less than 0.02 m	6.9
Snow, 0.02-0.2 m depth	17.3

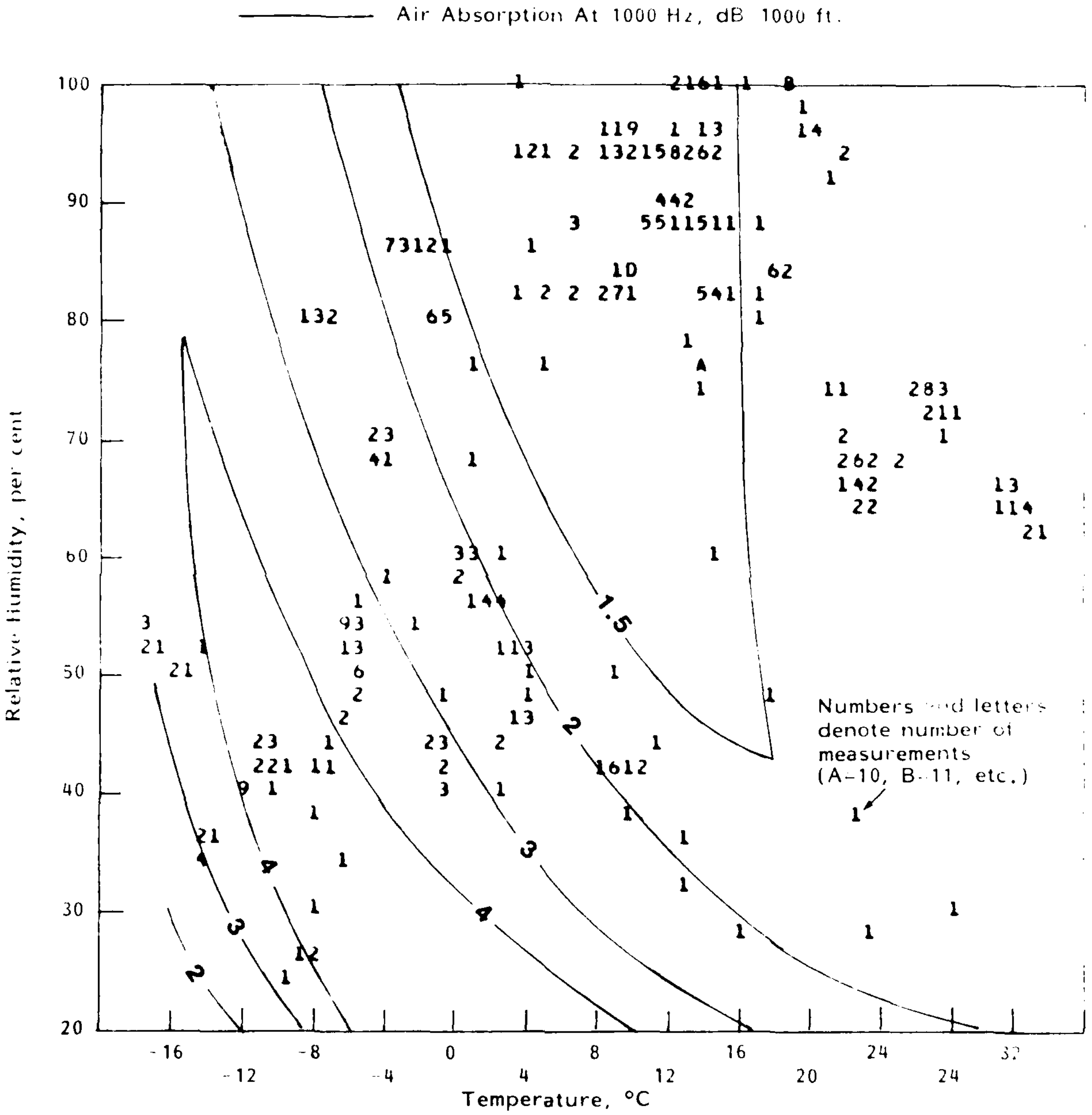


FIGURE 2. FIELD RELATIVE HUMIDITY VERSUS FIELD TEMPERATURE

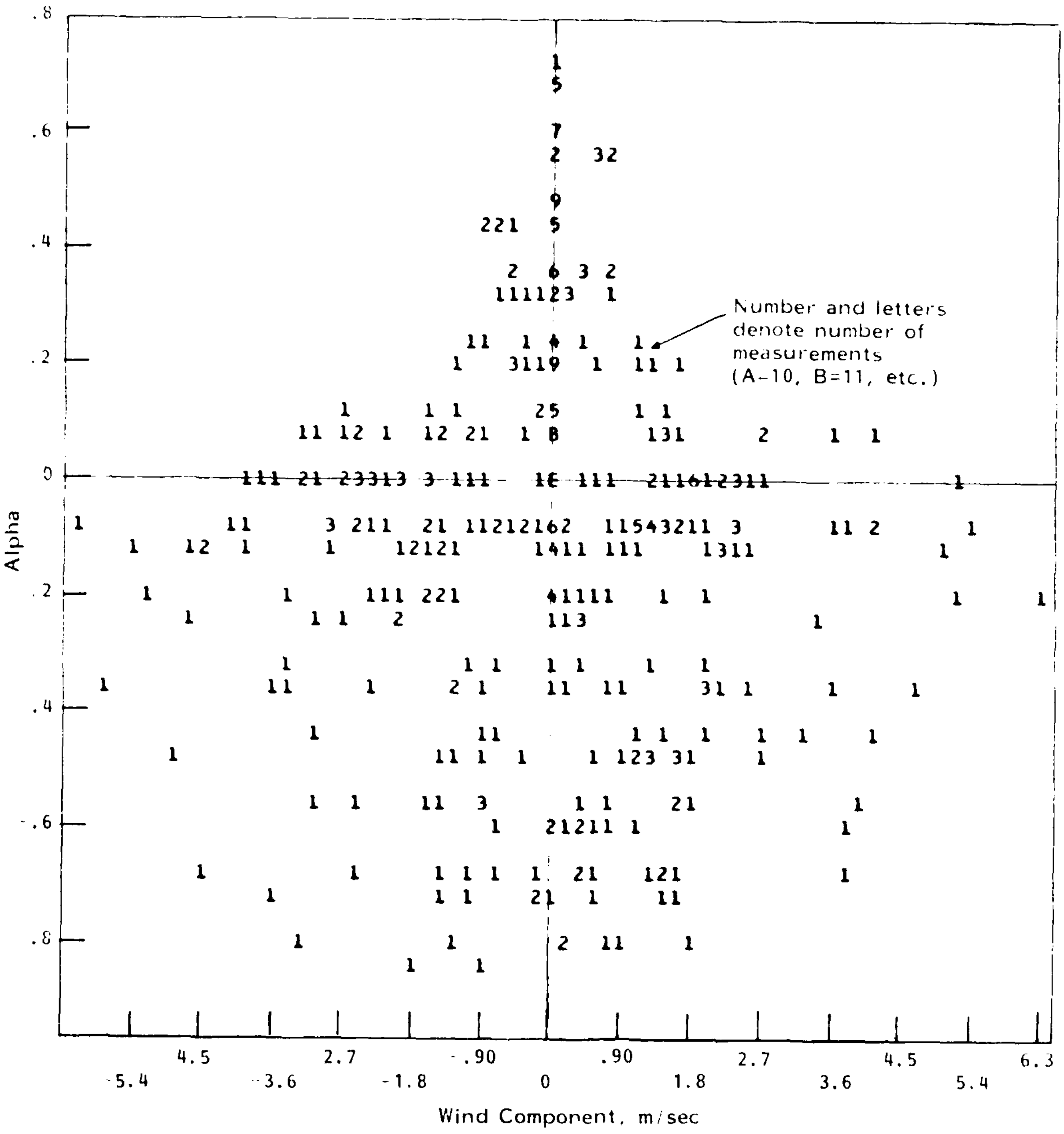
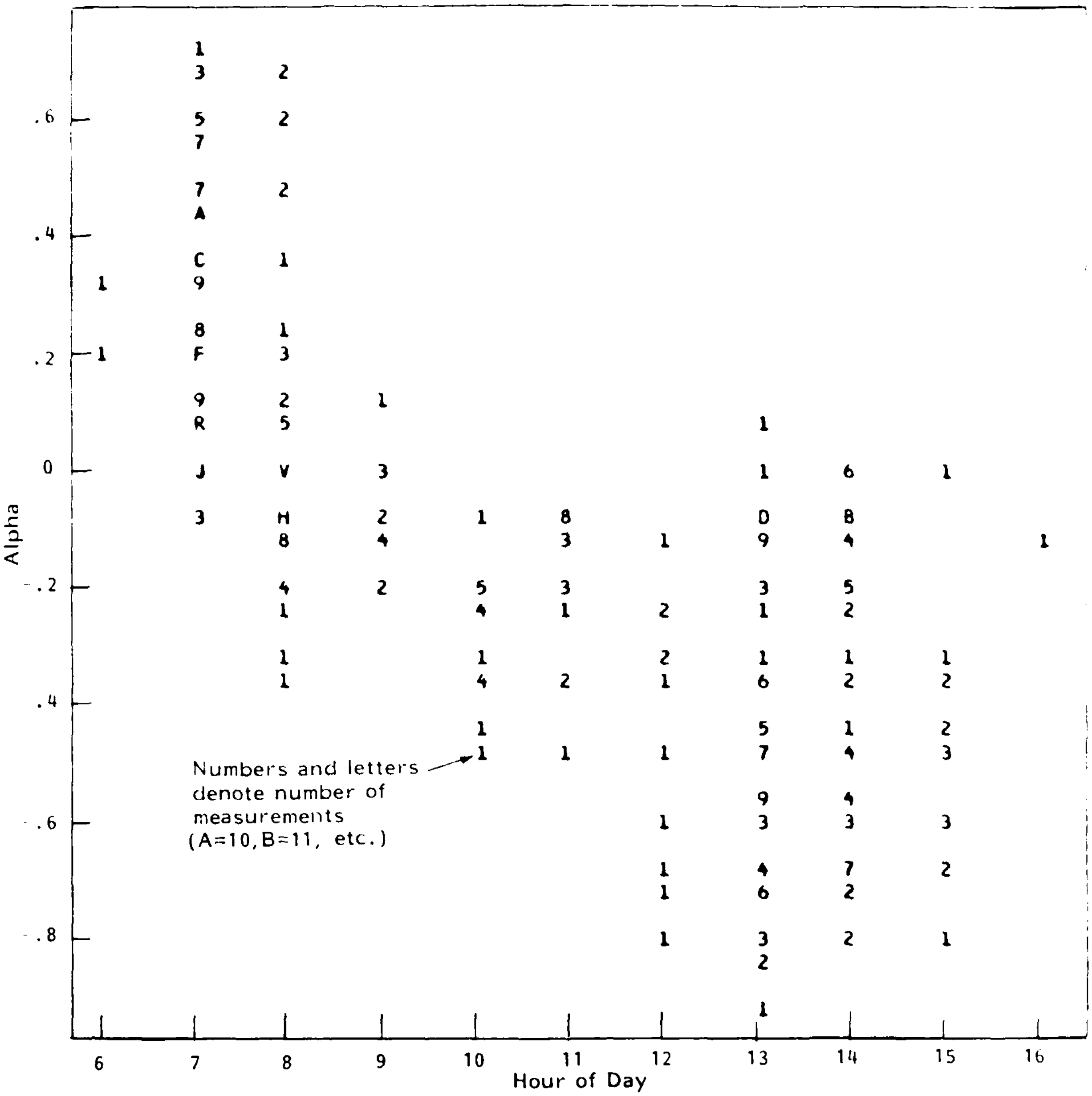


FIGURE 3. SCATTER PLOT OF ALPHA (TEMPERATURE GRADIENT) VERSUS WIND COMPONENT



Numbers and letters denote number of measurements (A=10, B=11, etc.)

FIGURE 4. SCATTER PLOT OF ALPHA (TEMPERATURE GRADIENT) VERSUS TIME OF DAY OF MEASUREMENTS

During the program, station meteorological data was collected together with site data. Comparisons of the two are of interest in seeing how well on-site measurements might agree with typical station measurements. The comparisons of temperatures show very high correlations ($r^2 = 0.98$). The comparisons of relative humidity showed a much lower value ($r^2 = 0.50$) while the correlations of wind speed and wind component showed intermediate correlations ($r^2 = 0.75$ and 0.80, respectively).

2.5 ESA Variability

Table 4 lists ranges in measured excess attenuation data for selected one-third octave frequency bands and the overall and A-levels at each distance. The table shows the number of measurements and the ranges for all, 50 percent, and 90 percent of the data. As anticipated, there was large variability in measured ESA values during the program. To indicate the extent of variability, Figures 5 and 6 show the range of measured ESA values, the mean values, and standard deviations for the measured values at two distances, 431 m (1414 ft) and 2087 m (6847 ft).

The general increase in the variability of ESA values with distance and with frequency is further shown in Figure 7. Figure 7 shows the range for 50 percent of the ESA values as a function of distance for selected one-third octave bands and for the overall and A-weighted sound levels. The general trend is for the range to increase with distance, reaching a maximum spread of the order of 12 to 18 dB.

TABLE 4. RANGE IN MEASURED EXCESS ATTENUATION DATA FOR SELECTED FREQUENCY BANDS

Frequency Band	Distance m	Distance ft	No. of Meas.	Range in Excess Attenuation Data, dB 50%	90%	All
63 Hz	134	440	369	2.4	5.2	14.1
	238	781	404	3.6	10.4	13.5
	427	1401	404	4.8	16.8	21.8
	753	2470	351	7.0	24.0	32.1
	1255	4117	375	10.0	28.0	35.7
	1757	5764	322	11.0	24.0	34.8
	2083	6834	308	10.8	21.0	37.0
	2273	7457	150	12.0	22.0	26.9
	2377	7799	247	10.0	23.0	37.0
250 Hz	134	440	367	8.0	14.4	28.0
	238	781	403	11.0	20.5	35.1
	427	1401	401	10.8	22.8	41.9
	753	2470	338	9.6	24.0	40.3
	1255	4117	380	10.8	34.2	56.0
	1757	5764	311	12.8	37.5	51.2
	2083	6834	331	15.0	34.5	53.0
	2273	7457	140	18.0	36.0	46.2
	2377	7799	261	16.5	34.5	45.8
1000 Hz	134	440	300	9.0	22.0	31.3
	238	781	404	14.4	27.0	38.1
	427	1401	402	16.8	25.0	46.7
	753	2470	354	16.2	30.0	43.9
	1255	4117	396	15.75	30.0	54.8
	1757	5764	350	16.5	31.5	52.8
	2083	6834	322	14.4	33.0	41.3
	2273	7457	170	13.2	28.9	42.0
	2377	7799	271	14.0	26.8	42.4
2000 Hz	134	440	360	8.0	20.0	31.3
	238	781	401	12.0	24.5	35.4
	427	1401	399	12.5	25.5	36.0
	753	2470	345	12.0	28.2	40.1
	1255	4117	356	13.5	31.5	48.6
	1757	5764	264	14.4	36.0	55.7
	2083	6834	225	14.4	27.0	56.0
	2273	7457	111	10.5	27.0	53.4
	2377	7799	170	13.5	25.5	56.7

TABLE 4. RANGE IN MEASURED EXCESS ATTENUATION DATA FOR SELECTED FREQUENCY BANDS (CONTINUED)

Frequency Band	Distance m	Distance ft	No. of Meas.	Range in Excess Attenuation Data, dB 50%	90%	All
OA	134	440	364	3.5	9.0	15.9
	238	781	404	3.8	12.5	17.8
	427	1401	405	4.0	13.0	30.0
	753	2470	355	6.0	20.0	35.1
	1255	4117	400	10.5	26.25	50.7
	1757	5764	367	12.0	28.5	50.9
	2083	6834	385	15.0	32.0	64.8
	2273	7457	195	18.8	31.5	53.4
AL	134	440	369	6.0	14.4	21.6
	238	781	404	9.6	22.4	29.4
	427	1401	405	13.2	25.2	37.3
	753	2470	355	14.4	30.0	43.6
	1255	4117	400	16.2	32.4	60.4
	1757	5764	367	16.2	36.0	62.0
	2083	6834	385	18.0	42.0	97.0
	2273	7457	195	18.0	53.0	71.9
	2377	7799	328	16.0	47.0	70.6

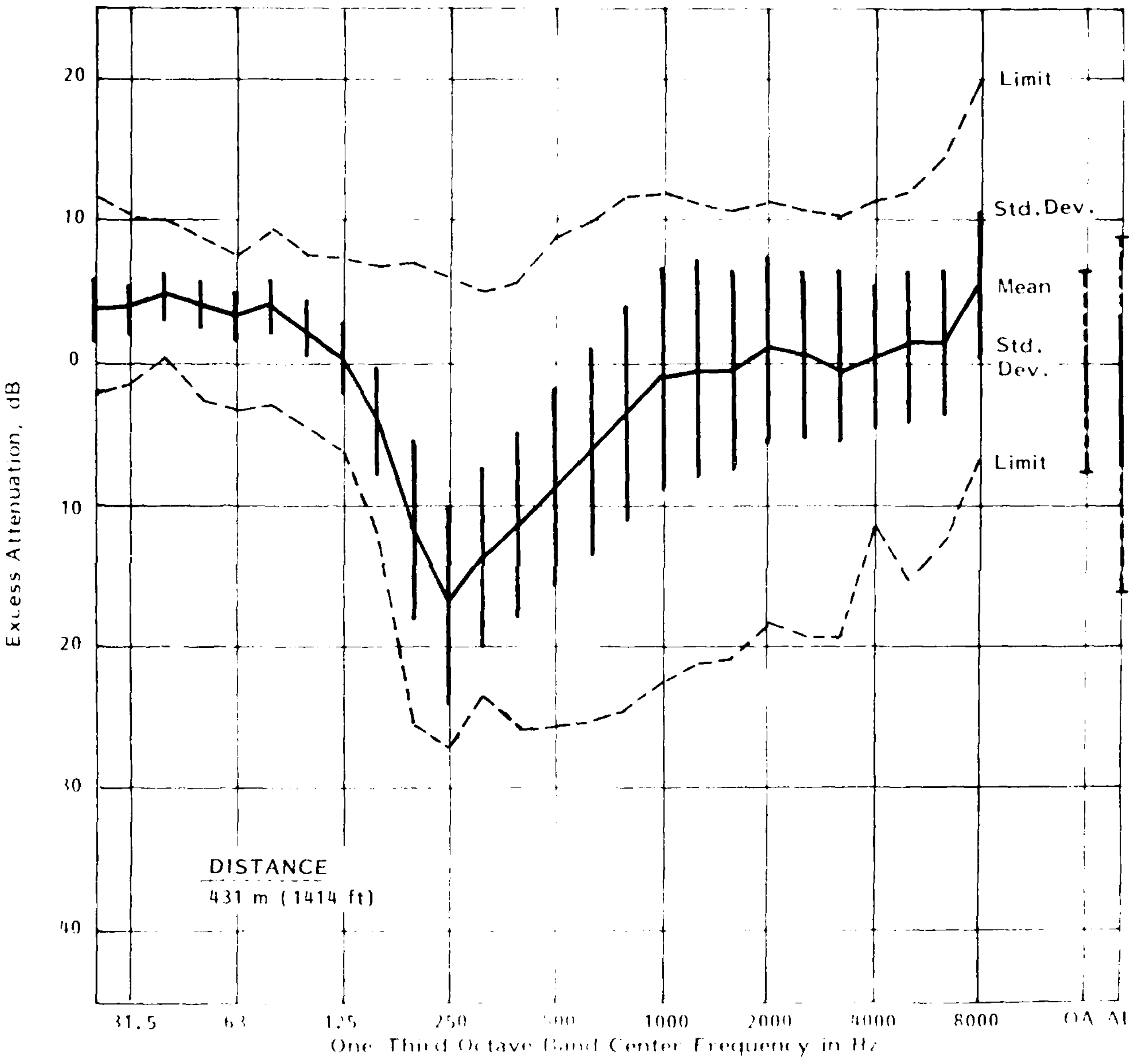


FIGURE 5. MEANS, STANDARD DEVIATIONS, RANGES OF MEASURED EXCESS ATTENUATION VALUES

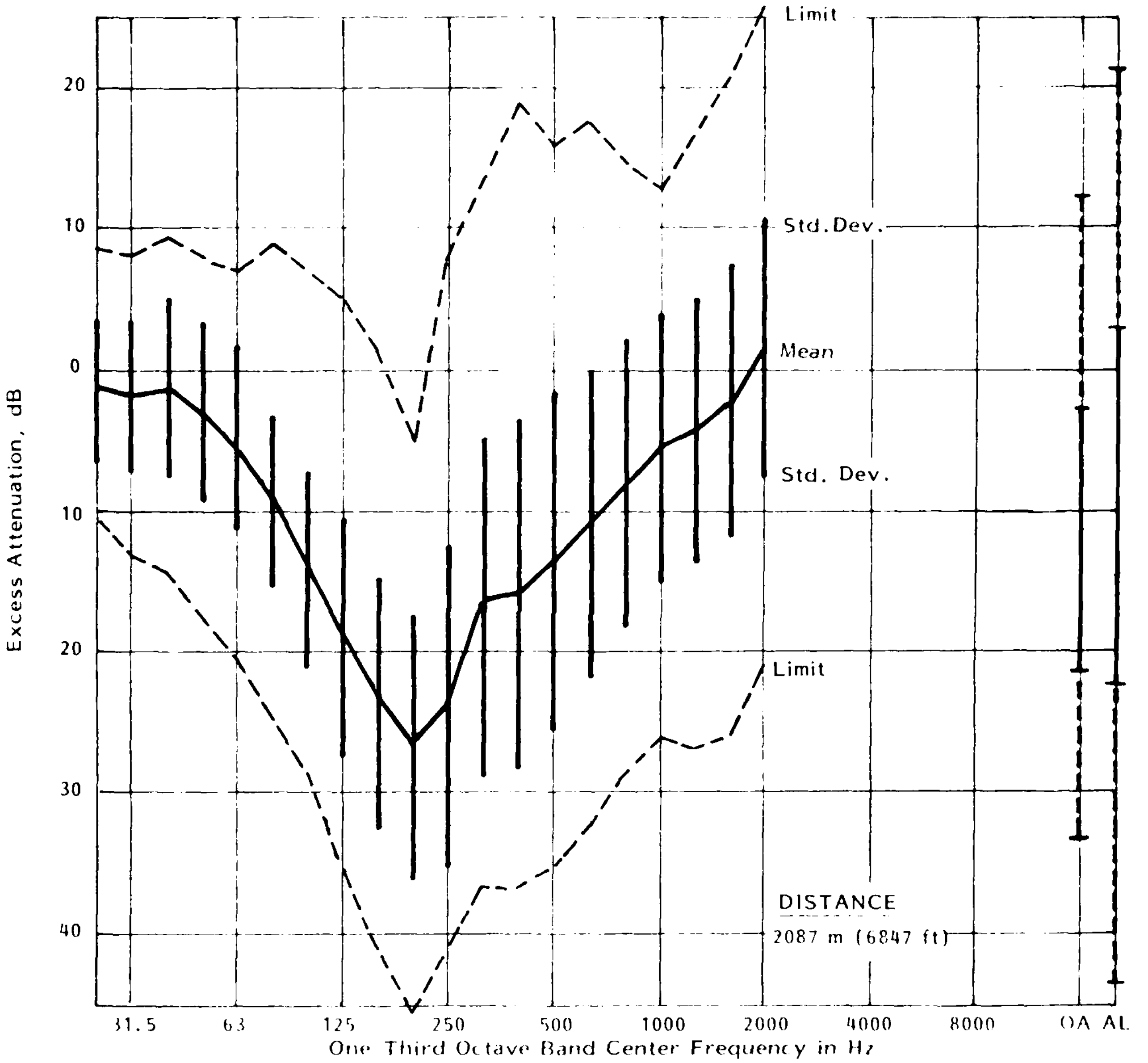


FIGURE 6. MEANS, STANDARD DEVIATIONS, RANGES OF MEASURED EXCESS ATTENUATION VALUES

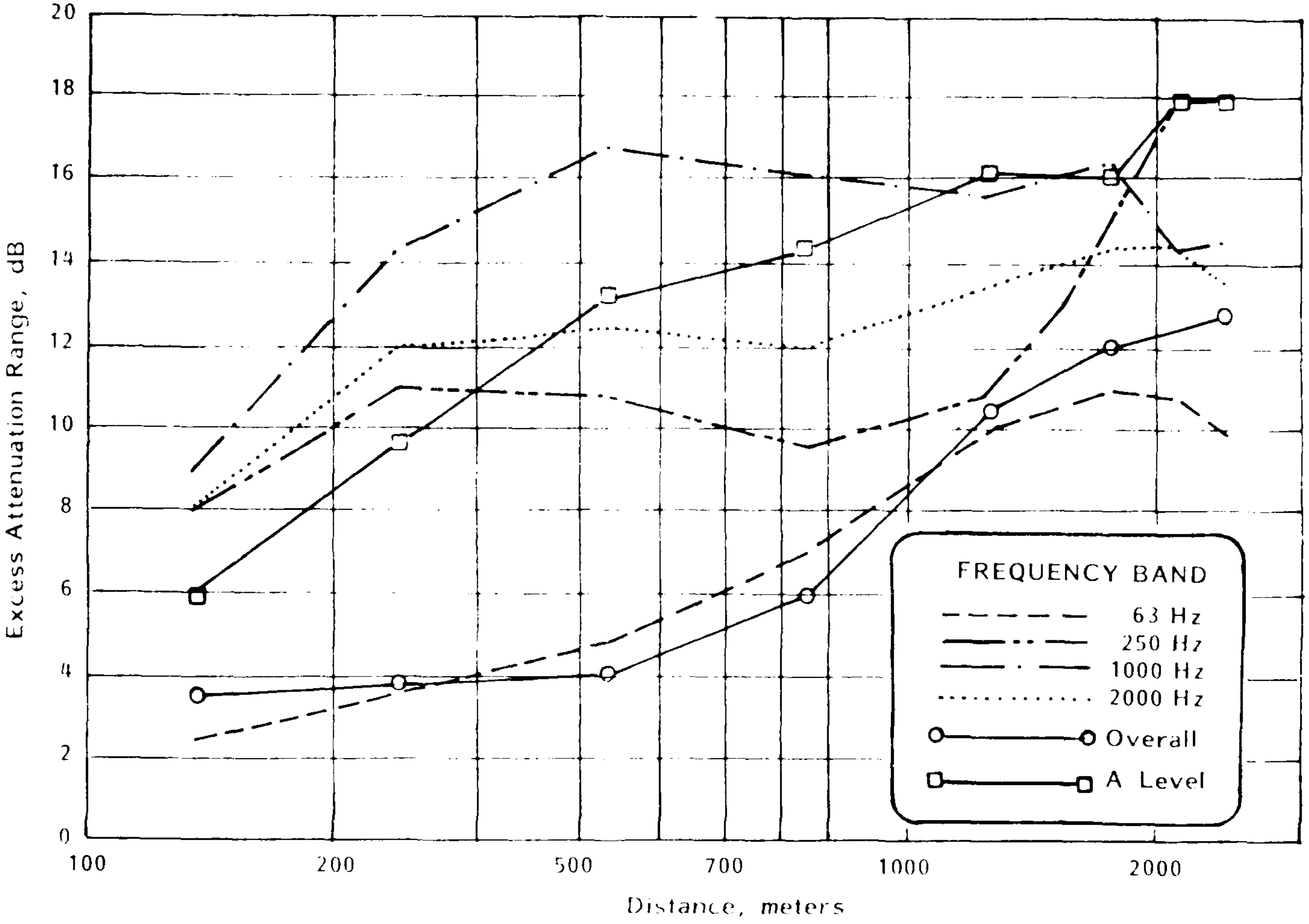


FIGURE 7. RANGE FOR FIFTY PERCENT OF MEASURED EXCESS ATTENUATION VALUES

At any given distance, the spread in ESA values generally increases with frequency up to about 1000 Hz with the range tending to decrease at higher frequencies.*

2.6 Noise Spectra at Reference Positions

The average noise spectrum at the reference positions was computed in two ways. In one case, the averages for each third octave band plus the averages for the A-levels and overall sound pressure levels were computed. These are given in Table 5 and shown in Figure 8. Also shown is the standard deviation for the measurements. Also listed in Table 5 and Figure 8 is the average normalized spectrum, with all levels referenced to the measured overall sound pressure level for each run. This adjusts for gross differences in source output and results in a lower standard deviation as indicated in the lower portion of Figure 8. The root mean square standard deviation over all the one-third octave bands for all runs for the measured spectrum was 4.0 dB.** For the one-third octave band levels referenced to the overall, the root mean square standard deviation was 2.4 dB.

As expected, measurements made over a short time period and/or with fewer positioning changes in aircraft show much smaller variation. For example, on one day, some 31 measurements were taken over an approximately 90-minute period with 15 events measured along array 03 and 16 measurements in the opposite direction along array 04. The average noise spectra for these

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*The reduced spread of data at higher frequencies is partially due to the loss of ESA data at the high frequencies, as discussed in Section 2.7.

**An average for only the events which used the C-135A aircraft and the average output from two microphones shows a slightly smaller standard deviation of 3.3 dB averaged over the 27 one-third octave bands.

TABLE 5. AVERAGE NOISE SPECTRA
AT REFERENCE MICROPHONES

Frequency Band	No. of Meas.	Sound Pressure Level, dB Mean	Sound Pressure Level, dB S.D.	Normalized Level, dB* Mean	Normalized Level, dB* S.D.
25	421	[illegible]	2.446	[illegible]	[illegible]
31.5	421	104.4	[illegible]	[illegible]	[illegible]
40	421	107.8	2.402	[illegible]	[illegible]
50	421	[illegible]	[illegible]	[illegible]	[illegible]
63	421	114.3	2.424	[illegible]	[illegible]
80	421	[illegible]	2.516	[illegible]	[illegible]
100	421	120.0	[illegible]	[illegible]	[illegible]
125	421	[illegible]	[illegible]	[illegible]	[illegible]
160	421	122.9	4.113	[illegible]	[illegible]
200	421	121.6	[illegible]	[illegible]	[illegible]
250	421	118.5	[illegible]	[illegible]	[illegible]
315	421	118.3	[illegible]	[illegible]	[illegible]
400	421	117.2	[illegible]	[illegible]	[illegible]
500	421	116.1	[illegible]	[illegible]	[illegible]
630	421	[illegible]	[illegible]	[illegible]	[illegible]
800	421	[illegible]	[illegible]	[illegible]	[illegible]
1000	421	[illegible]	[illegible]	[illegible]	[illegible]
1250	421	[illegible]	[illegible]	[illegible]	[illegible]
1600	421	111.2	[illegible]	[illegible]	[illegible]
2000	420	[illegible]	[illegible]	[illegible]	[illegible]
2500	402	108.8	[illegible]	[illegible]	[illegible]
3150	402	105.4	[illegible]	[illegible]	[illegible]
4000	372	105.6	[illegible]	[illegible]	[illegible]
5000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8000	304	102.1	[illegible]	[illegible]	[illegible]
10,000	295	102.4	[illegible]	[illegible]	[illegible]
Overall	421	130.7	[illegible]	[illegible]	[illegible]
A-Level	421	[illegible]	[illegible]	[illegible]	[illegible]

*All levels are referenced to the overall SPL.

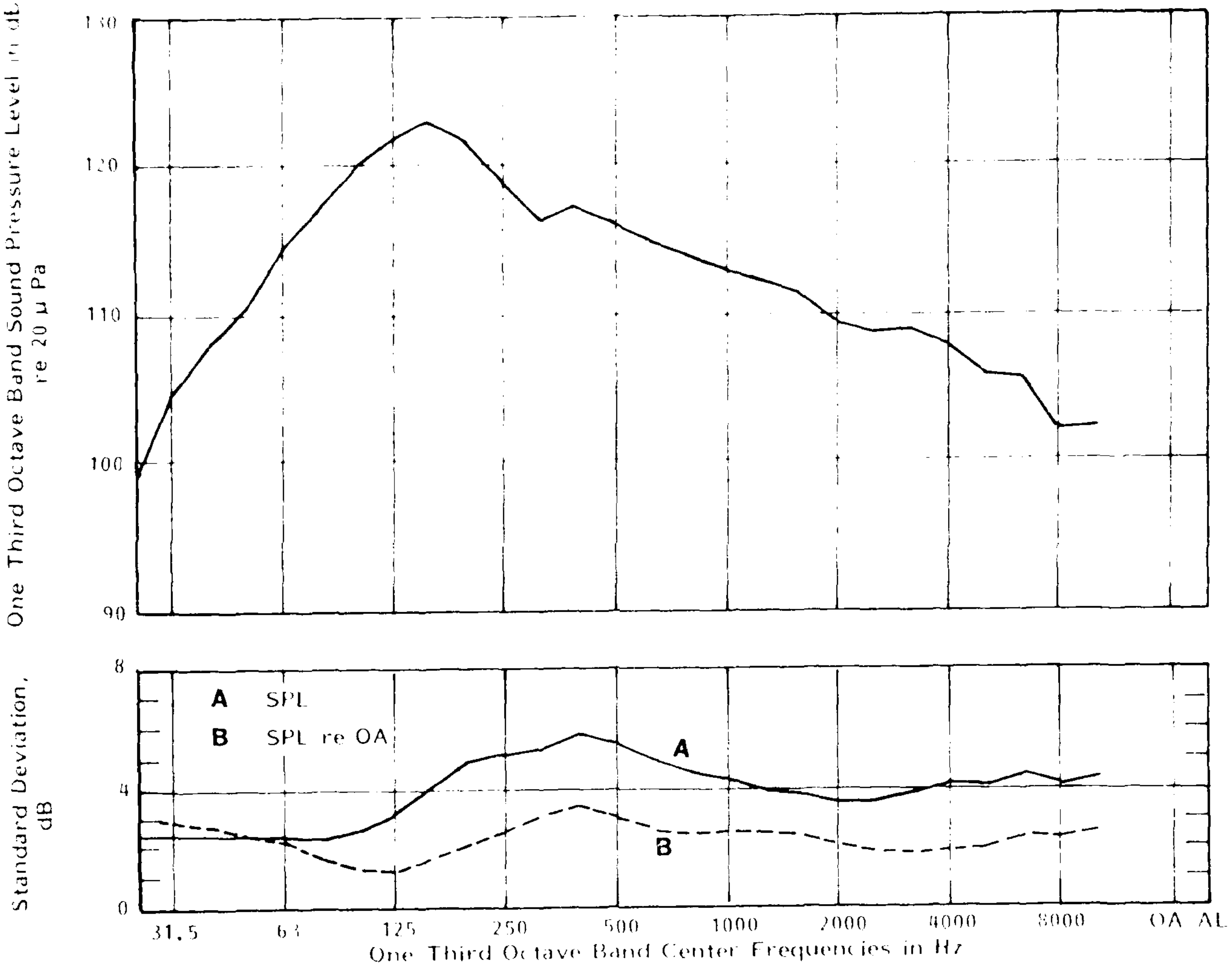

FIGURE 8. REFERENCE NOISE SPECTRA AND STANDARD DEVIATION 421 EVENTS

two sets of measurements are shown in Figure [illegible]. For these short-term measurements, the standard deviation averaged over the [illegible] one-third octave bands is of the order of [illegible] dB, appreciably less than the standard deviation for the whole set of measurements.*

Part of the difference in spectrum levels at the two reference positions is accounted for by the difference in distance from the engine source. However, above about [illegible] Hz, the differences are larger than the inverse-square adjustment. The larger differences are probably due to the larger extent of concrete between the engine and reference position for array [illegible], as discussed later in Section [illegible].

2.7 Short-Term Variations in ESA Values

The analyses discussed in the following sections will be concerned with extracting trends in ESA values from the set of measurements made over an extended period of time and obtained over a relatively wide range of meteorological conditions. The short-term variations in ESA values are also of practical interest since they provide an indication of the kind of changes in measured noise levels that can occur over short time periods.

The set of 31 measurements made in an approximate 90-minute period, discussed in the previous subsection, were examined to determine the variation in excess attenuation as a function of frequency and distance.

Table 6 summarizes the meteorological and surface conditions for the measurements. The winds were generally light and variable and the other meteorological conditions were reasonably

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*The variations in excess sound attenuation measured over this short interval are discussed later in this Section.

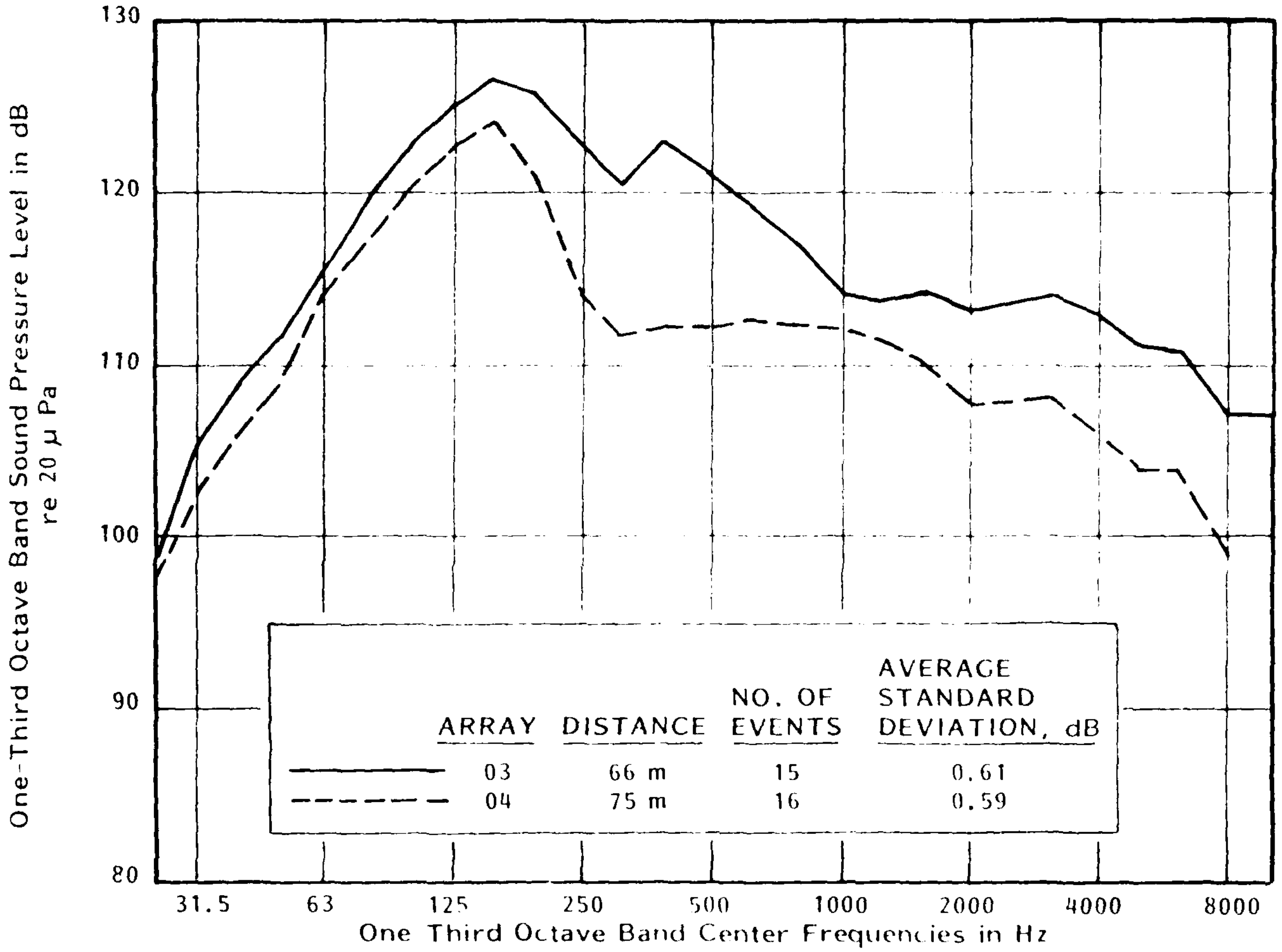

FIGURE 9. COMPARISON OF REFERENCE NOISE SPECTRA - REPEAT MEASUREMENTS OVER 90 MINUTE PERIOD

TABLE 6. METEOROLOGICAL AND SURFACE CONDITIONS DURING REPEAT MEASUREMENTS OVER 90-MINUTE PERIOD

Time of measurements - 7 am to 8:30 am

Number of measurements - 31

Ground cover conditions - grass with dew, on dry ground

	Mean	Range
Temperature	12°C	9.5 to 14.[illegible]°C
Relative humidity	92%	88 to 94%
Wind Speed	0.214 m/sec	0 to 0.65 m/sec
Alpha	0.15	-0.2 to 0.7

Measurements began under bright, clear conditions with heavy patches of fog on ground; fog dissipated during the measurements. Alpha began with high positive value (+0.7) and steadily decreased, ending with -0.2 value.

stable with the exception of the temperature gradient where alpha varied systematically with time, beginning with a high positive value and ending with a small negative value.

Standard deviations for the ESA values were calculated for each one-third octave band as well as the A-level and overall level for the measurements made over each array. The average standard deviation from these two sets of values was computed and averaged over several frequency ranges.* Figure 10 shows the variability, in terms of the standard deviation, plotted as a function of distance. The average standard deviation for the frequency range 25 to 125 Hz is shown, as is the average for the frequency range from 160 to 800 Hz and 1000 to 2000 Hz, as well as the average computed over the wideband frequency range from 25 to 2000 Hz. Also shown are the standard deviations for the A-level and overall ESA values.

The curve for the lower frequencies (25 to 125 Hz) shows very small standard deviations at close-in distances of the order of 1/2 dB or less, increasing to the order of 2 to 3 dB at distances of 2000 to 3000 meters. Measurements in the frequency range from 160 to 800 Hz show much larger standard deviations (order of 2 dB at smaller distances increasing to the order of 6 dB at 3000 meters). The standard deviations for the higher frequency range (1000 to 2000 Hz) is similar to that for the 160 to 800 Hz range up to approximately 800 meters and shows a decrease in magnitude at larger distances.

Standard deviations over the entire frequency range and for the A-level and overall level show a general trend of increasing magnitude with distance out to approximately 1000 meters with a general leveling off of standard deviations of the order of 3 to 5 dB at 1000 meters and greater distances.

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*Standard deviations were calculated separately for each array to allow for the possible differences in ESA values with array direction.

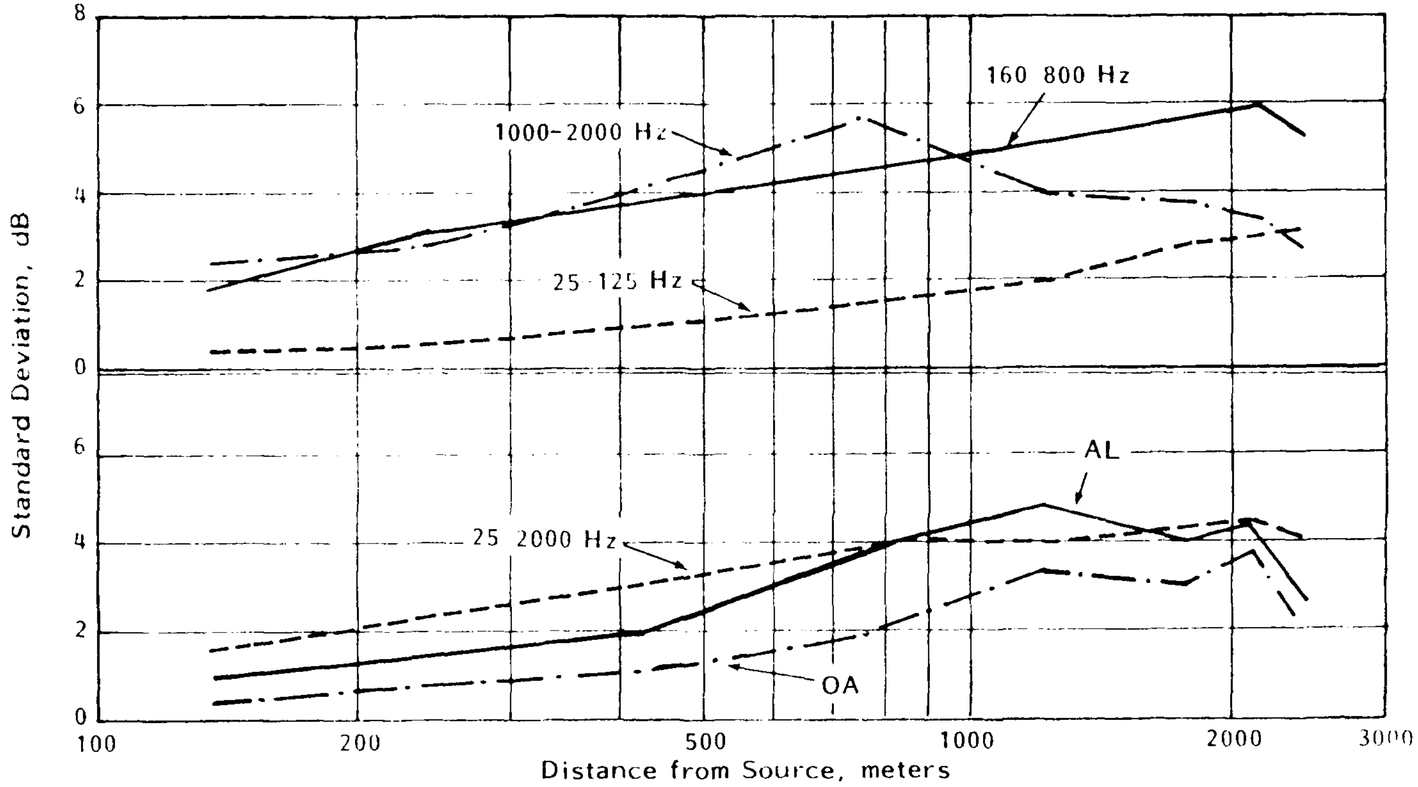

FIGURE 10. COMPARISON OF STANDARD DEVIATION FOR REPEAT MEASUREMENTS OF EXCESS ATTENUATION OVER A 90 MINUTE PERIOD

2.8 Loss of Noise Data with Increasing Distance and Frequency

At larger distances and higher frequencies, there is increased likelihood of data being lost by signal levels falling below ambient noise levels. This introduces a distinct bias in the measured ESA values that is difficult to compensate for. The average of "measured" ESA values obtained for those physical factors that tend to produce high excess attenuations will be lower than the "true" average values. The magnitude of this bias is difficult to determine.

Although the bias cannot be compensated for in its entirety, it is possible to determine the conditions under which data are lost and, hence, to be aware of those conditions for which the measured data are less representative.

As discussed in the next section, the wind component and temperature gradient were the most important meteorological variables affecting the measured ESA. The influence of these factors on the loss of ESA data can be assessed, in part, by comparing the joint distributions of these two parameters at distances and/or frequencies for which considerable ESA data have been lost.

As an example, Figure 11 shows the envelope of the joint distribution of alpha and wind component values for all data and for the data measured at a frequency of 4000 Hz at a distance of 753 meters (at this frequency and distance there were 108 data sets compared with a total of 421 for all data). In addition to the envelope, inner heavy lines show the ranges in alpha and wind component values for 50 percent of the data. The most significant loss of data occurs for negative wind component values, particularly under conditions of negative wind component and negative alpha values. With loss of data the average alpha and wind component values for which ESA values are measured shift to more positive values.

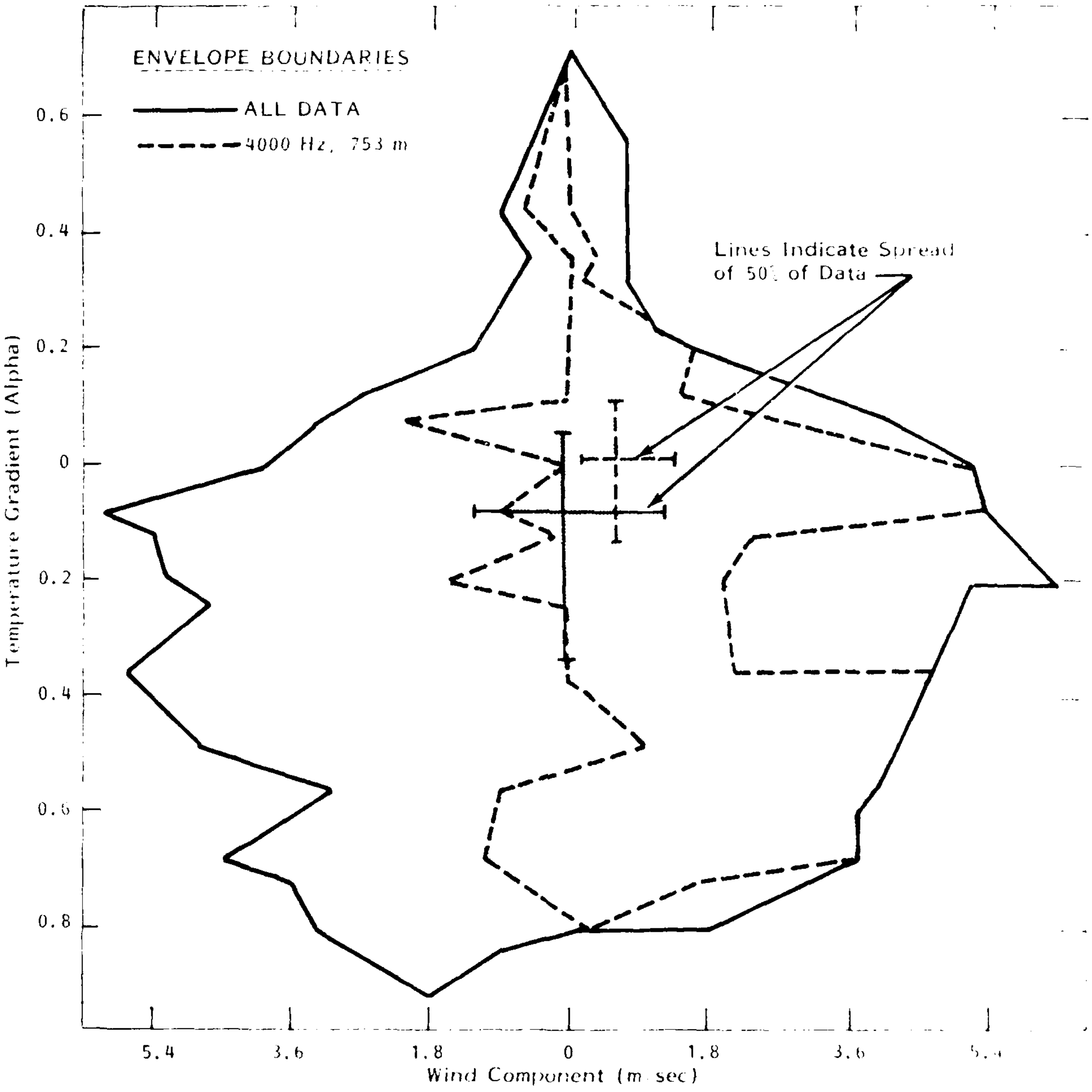

FIGURE 11. ENVELOPE OF ALPHA AND WIND COMPONENT VALUES ALL MEASUREMENTS VS. HIGH FREQUENCY MEASUREMENTS

The above trends are also shown by the information tabulated in Table 7, which shows the percent of ESA data measured under different alpha and wind component conditions. Here values are shown for all the data and for measurements at 4000 Hz at 753 meters and for a frequency of 2000 Hz at a distance of 2377 meters. At higher frequencies and greater distances, much less data is acquired for negative alpha values and wind component values.

TABLE 7. DISTRIBUTION OF MEASURED ESA DATA WITH ALPHA AND WIND COMPONENT AT DIFFERENT FREQUENCIES OR DISTANCES

		Percent of ESA Data		
Alpha		All Data (N=42[illegible])	2000 Hz, ≤37 m (N=170)	4000 Hz, 75 m (N=[illegible])
≥ 0		4[illegible]	[illegible]4.1	[illegible]
< 0		[illegible]	[illegible]	[illegible]
		1[illegible]	100.0	[illegible]
Wind Component				
> 0		4[illegible]	[illegible]	4[illegible]
0		1[illegible]	30.0	4[illegible]
< 0		[illegible]	1[illegible]	1[illegible]
		1[illegible]	[illegible]	[illegible]
Alpha	Wind Component			
≥ 0	> 0	[illegible]	[illegible]	[illegible]
	0	[illegible]	[illegible]	[illegible]
	< 0	1[illegible]	1[illegible]	[illegible]
< 0	> 0	27.[illegible]	[illegible]	[illegible]
	0	[illegible]	[illegible]	[illegible]
	< 0	[illegible]	[illegible]	[illegible]
		100.[illegible]	10[illegible]	[illegible]

3.0 REGRESSION ANALYSES

Multiple linear regression analyses were undertaken to determine the extent of correlation between several meteorological and ground surface conditions and the observed ESA values. After some preliminary analyses, three independent values were assumed: the wind component, alpha (temperature gradient), and the ground surface condition (considered as either grass or snow-covered).

The BMDP P2R Stepwise Linear Regression Program (Reference 7) was employed to determine the linear correlation between the three variables and the ESA value at each frequency, as well as the overall and A-level, at each distance. This process results in an independent determination of the correlation of these three variables with ESA at each frequency at each distance, and a rank ordering of the variables with regard to the degree of correlation with the ESA value. The results of these analyses are summarized in Tables 8 and 9. Table 8 shows, for each frequency and each distance, the value of the variance accounted for (r^2) for the first variable and for all of the three variables, the order in which the variables were selected, the standard deviation for the ESA values and the standard error for the completed regression analysis.

Figures 12-A through 12-I show the variance accounted for (r^2) as a function of frequency. The symbols denote the most significant variable. Figures 13-A and 13-B show the variance accounted for as a function of distance for six frequencies spaced at octave intervals from 63 to 2000 Hz.

Review of Figures 13-A and 13-B indicates that, as might be anticipated, the r^2 values generally decrease with distance, with the minor exception of 63 Hz values and with the more significant exception of the 250 Hz values where the r^2 values are very low (of the order of 0.2) irrespective of distance.

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS

					r^2		Order of Variables		
[illegible]	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	First	Last	a	b	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	
			[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS (CONTINUED)

Dist.	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	r First	r Last	Order of Variable (i) a	b	c
23m	25	398	2.3297	2.0367	0.1438	0.2395	2	–	[illegible]
(76	31	404	2.2778	1.9872	0.1537	0.2426	2	–	1
ft)	40	404	1.9961	1.7356	0.1600	0.1948	1	–	2
	50	403	2.0166	1.7967	0.1886	0.2121	1	2	3
	63	404	3.0274	1.7028	0.5233	0.6660	2	3	[illegible]
	80	404	4.2036	1.9785	0.6613	0.7801	2	3	[illegible]
	100	404	5.9122	2.3621	0.7681	0.8416	2	3	1
	125	404	6.4639	2.7559	0.7641	0.8202	2	–	[illegible]
	160	404	6.0842	3.6643	0.6017	0.6400	2	3	[illegible]
	200	404	6.0422	5.4216	0.1278	0.1389	–	1	2
	250	403	6.5407	5.7578	0.1544	0.2289	–	1	2
	315	404	6.1739	5.4319	0.1383	0.2317	1	3	2
	400	404	7.1287	5.6163	0.2651	0.3393	1	3	[illegible]
	500	404	7.6907	5.7884	0.3360	0.4377	1	2	[illegible]
	630	404	8.3007	5.8607	0.3814	0.5052	1	2	[illegible]
	800	404	8.7898	5.9849	0.4015	0.5398	1	2	3
	1000	404	8.8740	5.9511	0.4006	0.5525	1	2	–
	1250	404	8.7108	5.8484	0.4016	0.5515	1	[illegible]	–
	1600	404	8.4335	5.7867	0.4003	0.5327	1	2	[illegible]
	2000	401	7.9231	5.5970	0.3746	0.5047	1	[illegible]	3
	2500	372	7.4895	5.5545	0.3271	0.4544	1	2	3
	3150	364	7.0444	5.4641	0.2801	0.4033	1	2	3
	4000	354	6.7921	5.1563	0.3058	[illegible]	1	3	2
	5000	287	6.5610	5.4513	0.1886	[illegible]	1	3	[illegible]
	6300	217	5.5643	4.9940	0.1056	[illegible]	1	–	[illegible]
	8000	160	5.3529	4.9995	[illegible]	–	1	–	–
	A	404	3.3149	[illegible]	0.3046	[illegible]	1	[illegible]	[illegible]
	[illegible]	404	6.8519	4.7630	[illegible]	[illegible]	1		[illegible]

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS
(CONTINUED)

[illegible]	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	r First	r Last	Order of Variable [illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2660	[illegible]	2	–	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2765	0.4554	[illegible]	3	1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	0.2141	[illegible]	1	[illegible]	3
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	0.7964	[illegible]	[illegible]	3	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	[illegible]
	[illegible]	403	[illegible]	[illegible]	[illegible]	[illegible]	–	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	0.1476	[illegible]	[illegible]	[illegible]	–
	[illegible]	401	7.1775	[illegible]	[illegible]	[illegible]	[illegible]	3	1
	[illegible]	[illegible]	7.5556	[illegible]	[illegible]	[illegible]	1	–	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	[illegible]	403	9.4587	6.7477	[illegible]	[illegible]	1	[illegible]	–
	[illegible]	402	[illegible]	[illegible]	0.4034	[illegible]	1	[illegible]	–
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	–
	[illegible]	402	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1		[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		–
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS (CONTINUED)

Dist.	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	R First	R Last	Order of Variable In 1	2	3
75 SM.	25	344	[illegible]	[illegible]	[illegible]	0.4616	1	3	2
12471	31	352	[illegible]	[illegible]	0.2895	.4586	1	5	2
FT.	40	353	[illegible]	[illegible]	0.3495	.4672	1	2	3
	50	354	[illegible]	[illegible]	0.3003	0.5456	1	3	[illegible]
	63	351	7.7154	[illegible]	0.6634	0.7514	2	3	1
	80	341	[illegible]	[illegible]	0.6954	.7778	2	3	[illegible]
	100	344	9.5069	[illegible]	0.7161	0.7500	[illegible]	3	[illegible]
	125	341	[illegible]	[illegible]	0.4810	0.5242	2	—	[illegible]
	160	351	8.3967	[illegible]	0.2477	0.2665	2	—	[illegible]
	200	347	[illegible]	[illegible]	0.0640	0.0806	1	2	—
	250	330	7.4535	[illegible]	0.1198	0.2076	1	—	[illegible]
	315	352	8.4805	[illegible]	0.2525	0.2650	1	—	[illegible]
	400	354	9.4621	7.3211	[illegible]	0.3051	1	2	3
	500	354	9.7430	7.6955	0.3502	0.3737	1	2	—
	630	354	[illegible]	[illegible]	0.3686	0.4490	1	2	—
	800	354	9.5722	[illegible]	0.3804	0.4781	1	2	—
	1000	354	9.7609	[illegible]	0.3749	0.4754	1	2	—
	1250	344	9.3337	7.6077	0.3663	0.4396	1	2	—
	1600	351	[illegible]	6.4731	0.3589	0.4077	1	[illegible]	[illegible]
	2000	345	8.5101	6.7627	0.3248	0.3746	1	2	[illegible]
	2500	255	7.5736	[illegible]	0.1755	0.2467	1	2	[illegible]
	3150	207	8.5317	7.0176	0.1892	0.2974	1	—	[illegible]
	4000	[illegible]	6.5169	[illegible]	0.2703	0.3306	[illegible]	—	[illegible]
	A	355	[illegible]	[illegible]	[illegible]	.4216	1	2	—
	[illegible]	[illegible]	[illegible]	[illegible]	0.3605	[illegible]	1	[illegible]	[illegible]

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS (CONTINUED)

Dist.	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	r First	r Last	[illegible]	Order of Variable [illegible] 1	[illegible]
150[illegible] 41[illegible] ft	25	345	[illegible].8599	3.0[illegible]	0.1333	[illegible]	[illegible]	3	[illegible]
	31	373	4.5936	3.5077	0.3091	0.4633	[illegible]	[illegible]	[illegible]
	40	392	5.0966	[illegible]	0.4066	0.5066	[illegible]	[illegible]	—
	50	388	6.0858	[illegible]	0.2836	[illegible]	1	[illegible]	[illegible]
	63	375	7.46[illegible]	[illegible]	0.4755	[illegible]	[illegible]	[illegible]	[illegible]
	80	371	7.44[illegible]	[illegible]	0.3656	[illegible]	[illegible]	[illegible]	[illegible]
	100	351	8.307[illegible]	[illegible]	0.3761	[illegible]	[illegible]	[illegible]	[illegible]
	125	386	8.0632	[illegible]	0.2079	[illegible]	[illegible]	—	[illegible]
	160	391	7.9550	7.4911	0.0614	[illegible]	[illegible]	—	[illegible]
	200	388	8.6398	5.18[illegible]	0.0824	[illegible]	[illegible]	[illegible]	[illegible]
	250	370	9.0864	6.7189	0.1026	0.1[illegible]	[illegible]	—	[illegible]
	315	396	10.3574	[illegible].1527	0.1882	[illegible]	[illegible]	—	[illegible]
	400	397	10.8557	[illegible].9016	0.2306	[illegible]	[illegible]	—	[illegible]
	500	395	10.9333	[illegible]	0.28[illegible]	0.[illegible]	[illegible]	[illegible]	[illegible]
	630	399	10.7151	[illegible]	0.3169	[illegible]	[illegible]	[illegible]	[illegible]
	800	398	10.3224	7.[illegible]	0.3383	0.4127	[illegible]	[illegible]	[illegible]
	1000	396	9.8491	7.[illegible]	0.3465	0.4113	[illegible]	[illegible]	[illegible]
	1250	392	9.4134	7.[illegible]	0.3445	0.3[illegible]74	[illegible]	[illegible]	[illegible]
	1600	395	9.4976	7.[illegible]	0.3334	[illegible]	[illegible]	[illegible]	[illegible]
	2000	396	9.5634	7.[illegible]	0.2[illegible]	[illegible]417	[illegible]	[illegible]	[illegible]
	2500	148	8.60[illegible]	7.[illegible]	0.0[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	3150	172	8.338	[illegible]	0.0440	—	—	—	[illegible]
	A	40[illegible]	7.5[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	40[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS
(CONTINUED)

Dist.	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	r² First	r² Last	Order of Variable In a	Order of Variable In b	Order of Variable In c
1757m (5765 ft)	25	289	4.2628	3.6195	0.1611	0.2866	1	2	3
	31	336	5.0248	4.0545	0.2972	0.3529	1	2	–
	40	347	5.6696	4.1925	0.3096	0.4576	1	3	2
	50	339	6.8356	4.5272	0.2432	0.5653	2	3	1
	63	322	7.2604	4.6737	0.3619	0.5895	1	3	2
	80	321	7.3057	5.8614	0.2196	0.3761	2	3	1
	100	326	8.0069	6.5373	0.1999	0.3395	2	3	1
	125	336	8.5356	7.1768	0.1639	0.2969	2	–	1
	160	350	8.7480	8.2894	0.0782	0.1072	1	–	2
	200	327	9.8220	9.2241	0.0939	0.1235	1	–	2
	250	311	11.5153	10.4832	0.0967	0.1766	2	–	1
	315	355	12.1652	10.8943	0.1609	0.2025	1	–	2
	400	363	12.5295	11.0042	0.1869	0.2329	1	–	2
	500	363	12.1113	10.2684	0.2245	0.2871	1	3	2
	630	366	11.5518	9.5145	0.2531	0.3273	1	3	2
	800	361	11.0480	8.9691	0.2726	0.3464	1	3	2
	1000	356	10.3460	8.4417	0.2820	0.3462	1	3	2
	1250	348	9.9705	8.1436	0.2733	0.3397	1	3	2
	1600	323	10.4147	8.4261	0.2521	0.3415	1	3	2
	2000	284	10.6104	8.7522	0.1673	0.3275	1	–	2
	A	367	9.2965	7.4540	0.2859	0.3615	1	3	2
	C	367	11.6485	[illegible]	0.2483	0.3110	1	3	2

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS
(CONTINUED)

[illegible]	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	r First	r Last	Order of Variable a	Order of Variable b	Order of Variable c
[illegible]	25	358	[illegible]	[illegible]	[illegible]	[illegible]	1	2	3
[illegible]	31	[illegible]	[illegible]	[illegible]	[illegible]	0.4690	1	2	—
[illegible]	40	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	3	2
	[illegible]	341	[illegible]	[illegible]	[illegible]	[illegible]	1	3	2
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.3742	[illegible]	3	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	—	2
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2361	1	3	2
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	2	—
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	2	3
	[illegible]	[illegible]	[illegible]	[illegible]	0.2133	0.2833	1	2	3
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	2	—
	[illegible]	[illegible]	[illegible]	[illegible]	0.2914	[illegible]	1	2	—
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	2	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	2	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	0.1417	[illegible]	1	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	0.2675	[illegible]	[illegible]	2	—
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS (CONTINUED)

Dist.	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	r^2 First	r^2 Last	Order of Variable In a	Order of Variable In b	Order of Variable In c
2273m	25	153	4.8745	5.3594	0.2329	0.3489	1	2	–
(7455	31	176	6.7958	5.4347	0.2920	0.3714	1	2	–
ft)	40	185	7.2342	5.5261	0.2148	0.4664	1	3	2
	50	171	7.2613	5.5417	0.1698	0.4279	1	3	2
	63	156	7.1059	5.9137	0.1501	0.3208	1	3	2
	80	163	7.7739	6.5053	0.1299	0.3123	2	3	1
	100	168	8.2201	6.8810	0.1785	0.3118	2	3	1
	125	159	8.4011	7.4298	0.0763	0.2327	1	3	2
	160	158	7.5889	6.7790	0.1054	0.2122	2	1	–
	200	128	7.8670	6.3665	0.2686	0.3726	3	1	2
	250	146	11.7178	9.7385	0.2215	0.3236	2	1	3
	315	150	11.8780	9.6696	0.1929	0.3462	2	1	–
	400	176	13.1987	10.6163	0.2943	0.3604	1	2	–
	500	179	12.3576	9.5145	0.3460	0.4139	1	2	–
	630	177	11.2755	8.4948	0.3651	0.4389	1	2	–
	800	174	10.1283	8.1155	0.2718	0.3692	1	2	3
	1000	170	9.1355	7.5942	0.1909	0.3212	1	2	3
	1250	161	9.1177	7.4308	0.1762	0.3483	1	2	3
	1600	133	9.3256	7.2346	0.1813	0.4118	3	2	1
	2000	111	8.6695	7.4145	0.1392	0.2885	3	1	2
	A	195	10.6657	8.5295	0.3005	0.3995	1	2	3
	AL	195	14.7004	12.6715	0.2252	0.2646	1	–	2

TABLE 8. RESULTS OF ESA STEPWISE REGRESSION ANALYSIS (CONTINUED)

Dist.	Freq.	No. of Cases	ESA Std. Dev.	Regr. Std. Error	r First	r Last	Order of Variable 1	2	3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2266	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	7.7048	[illegible]	0.2374	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1047	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2604	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1545	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	5.1447	0.1711	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0736	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0620	[illegible]	[illegible]	1	–
[illegible]	[illegible]	[illegible]	[illegible]	9.9754	0.0947	[illegible]	2	1	–
[illegible]	[illegible]	[illegible]	11.7545	[illegible]	0.1199	0.2402	2	1	–
[illegible]	[illegible]	[illegible]	12.1209	[illegible]	0.1629	0.2836	[illegible]	[illegible]	–
[illegible]	[illegible]	[illegible]	[illegible]	9.2651	0.2018	[illegible]	1	[illegible]	–
[illegible]	[illegible]	[illegible]	[illegible]	9.4474	0.2267	[illegible]	1	[illegible]	–
[illegible]	[illegible]	[illegible]	[illegible]	7.9459	0.2317	0.3374	1	[illegible]	–
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2126	0.3045	1	2	–
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1559	[illegible]	1	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0987	[illegible]	3	1	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.0300	–	–	1	–
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.2377	[illegible]	1	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.1787	[illegible]	1	2	[illegible]

[illegible]

1 = [illegible]
2 = [illegible]
3 = [illegible]

TABLE 9. MAXIMUM r^2 VALUES AT EACH DISTANCE

Distance	First Maximum Freq. Hz	Max r^2	Most Significant Variable (1)	Second Maximum Freq. Hz	Max r^2	Most Significant Variable (1)
134 m (440 ft)	160	0.73	c	1250	0.59	a
238 m (781 ft)	100	0.84	c	1000	0.55	a
431 m (1414 ft)	80	0.83	c	1000	0.51	a
753 m (2471 ft)	80	0.78	c	800	0.48	a
1255 m (4118 ft)	63	0.68	c	800	0.41	a
1757 m (5765 ft)	63	0.59	c	1600	0.35	a
2087 m (6847 ft)	50	0.55	a	630	0.38	a
2273 m (7458 ft)	40	0.47	a	630	0.44	a
2377 m (7800 ft)	40	0.50	a	630	0.35	a

---

(1) Most significant variable
- (a) Wind component
- (b) Alpha (temperature gradient)
- (c) Ground cover

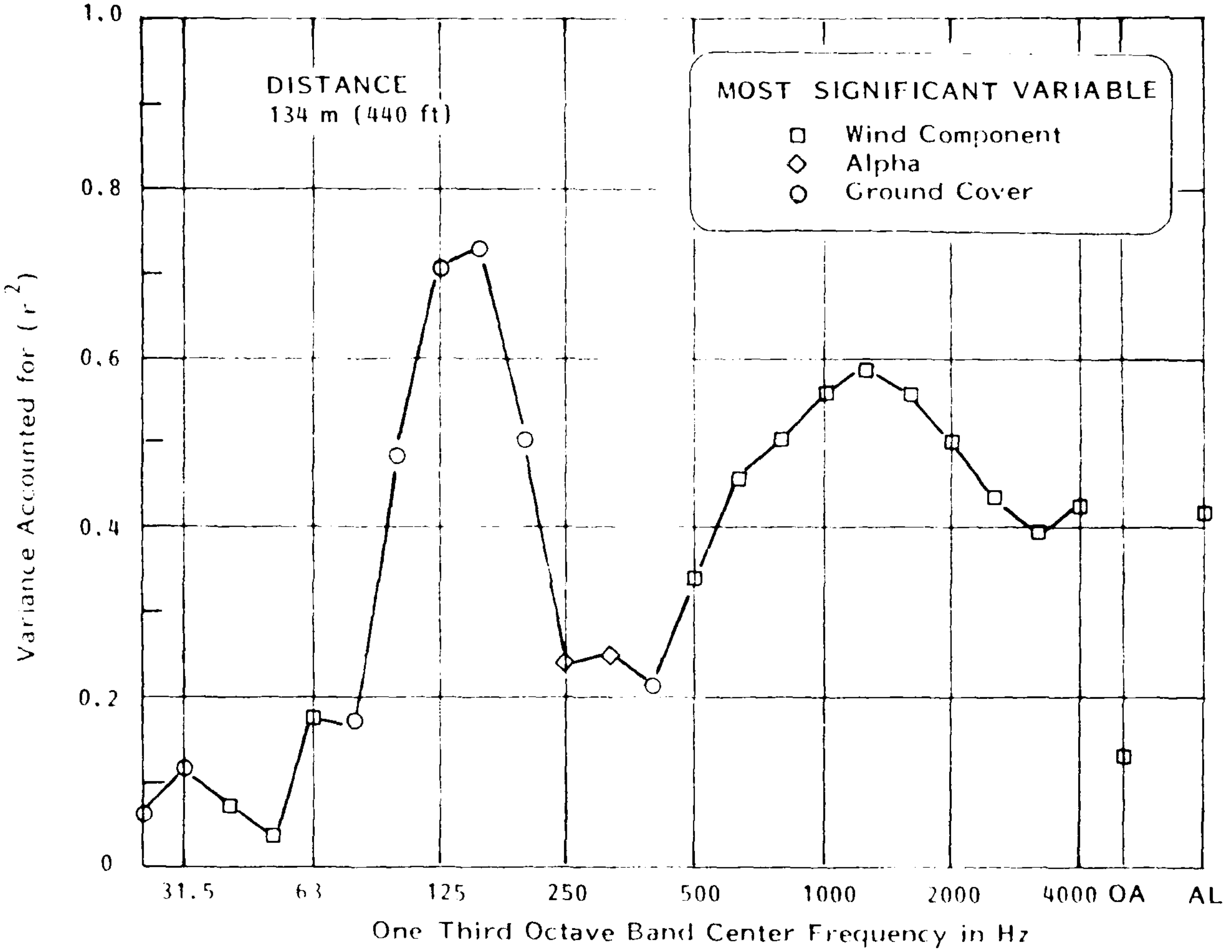

FIGURE 12 A. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER, DISTANCE 134 m

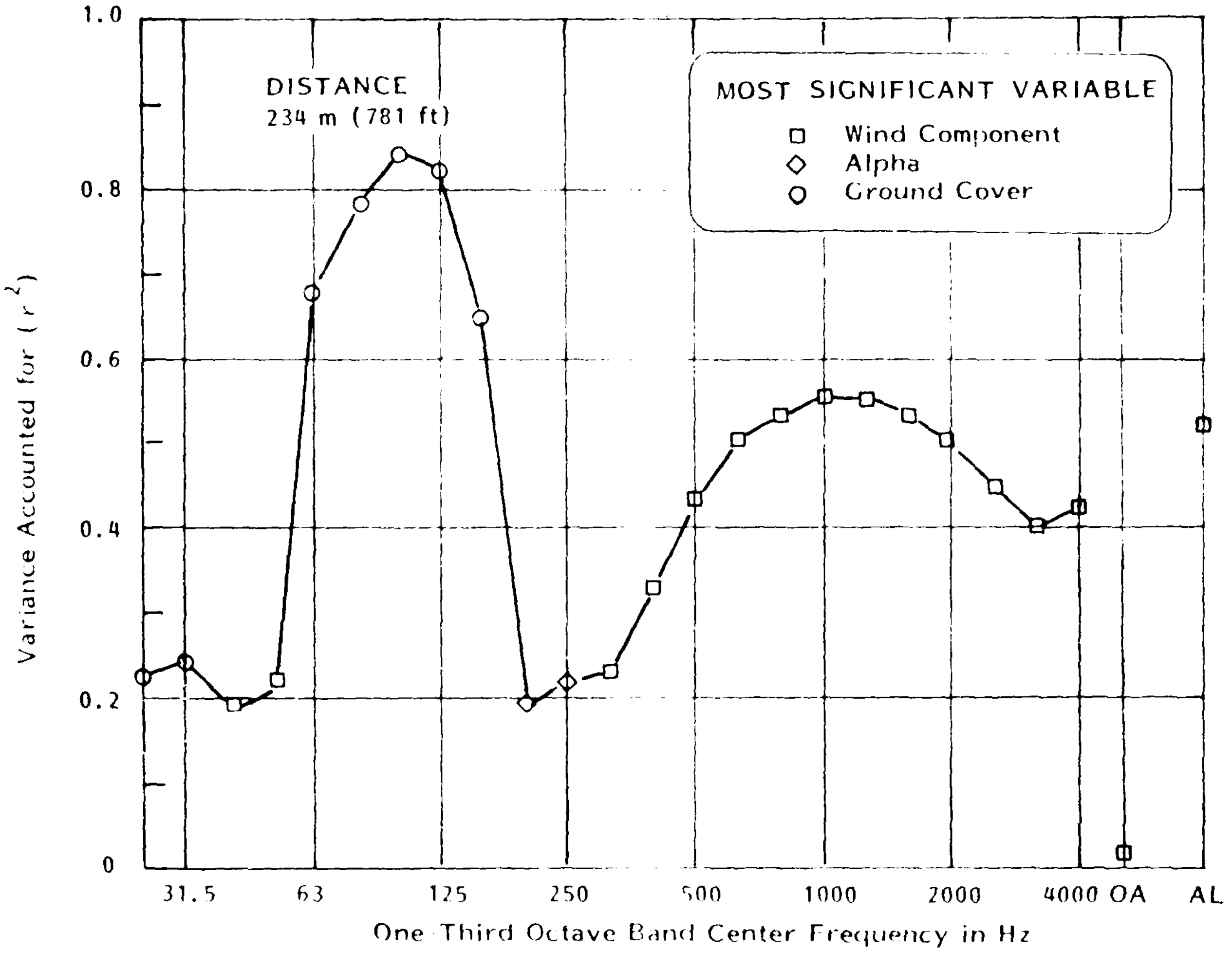

FIGURE 12 B. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER, DISTANCE 234 m

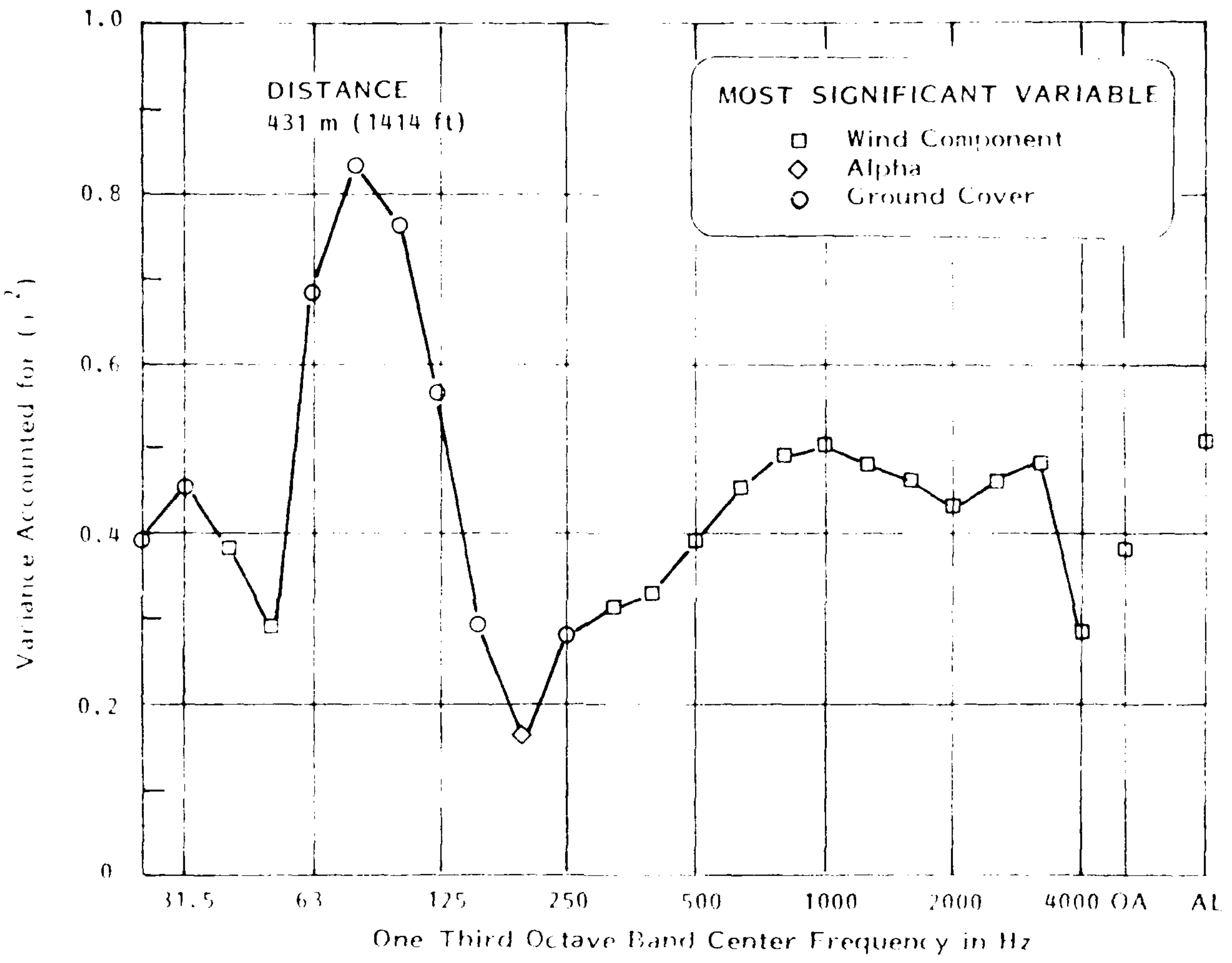

FIGURE [illegible]. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT
TEMPERATURE GRADIENT AND GROUND COVER
DISTANCE 431 m

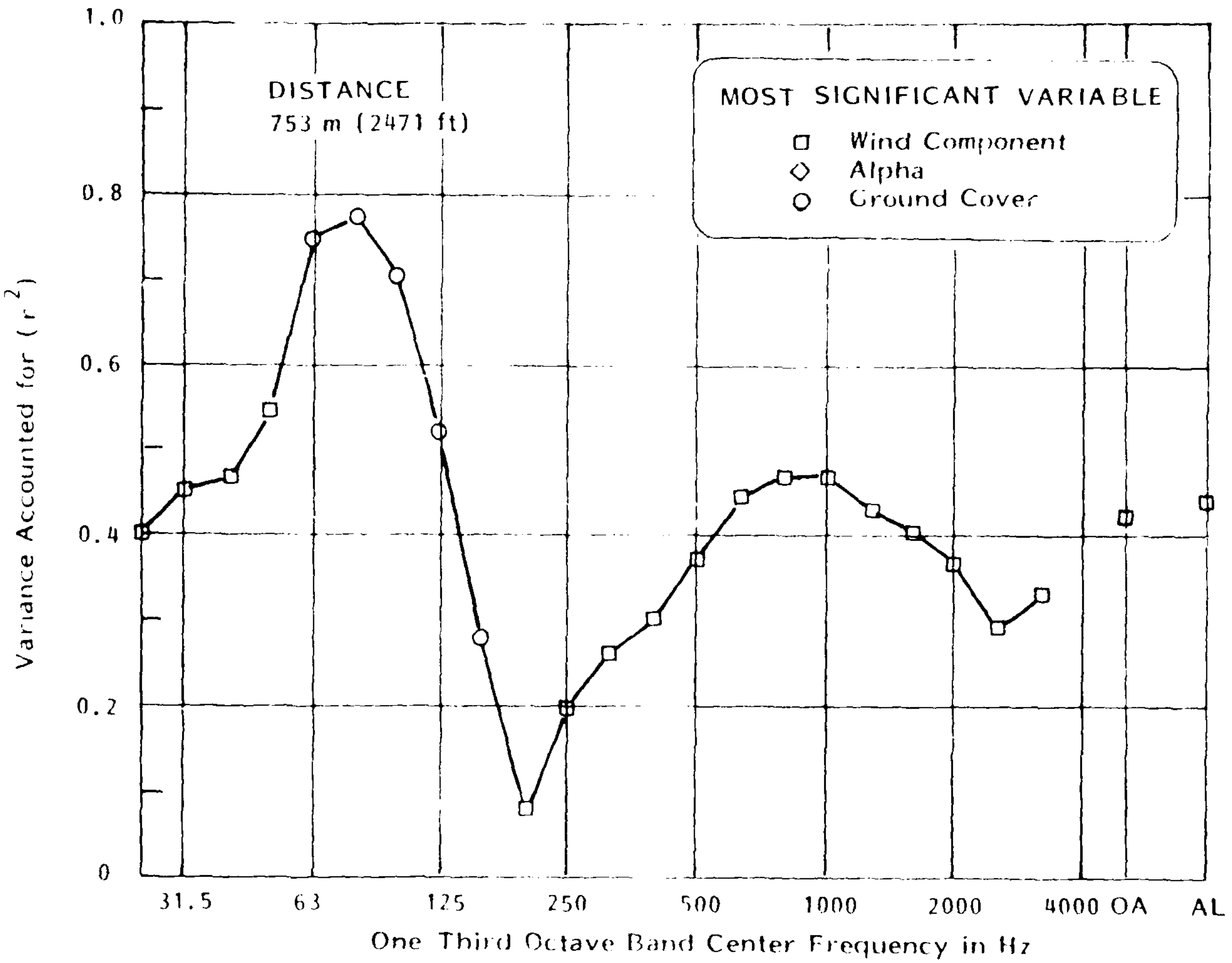

FIGURE 12 D. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER, DISTANCE 753 m

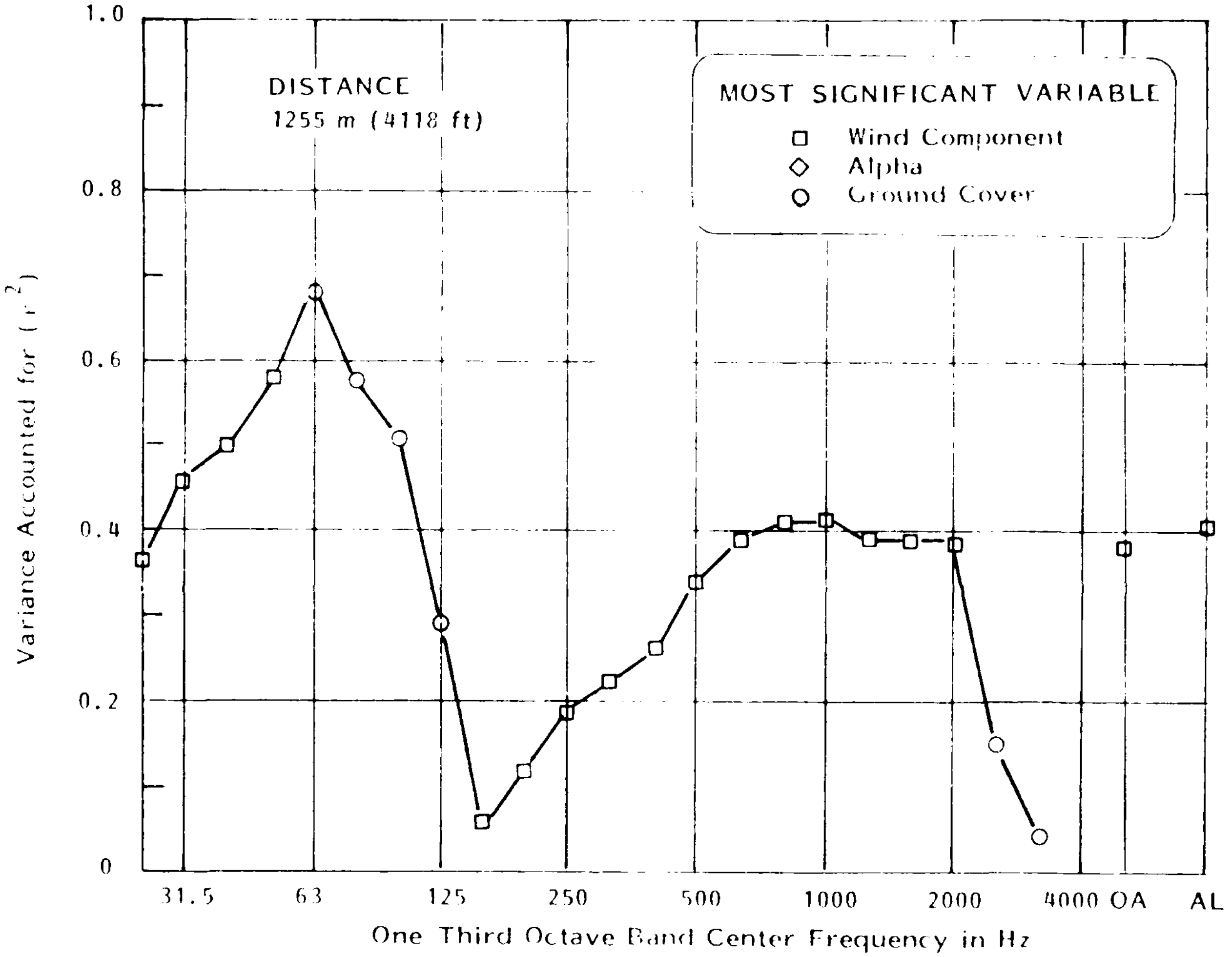

FIGURE 12 E. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER, DISTANCE 1255 m

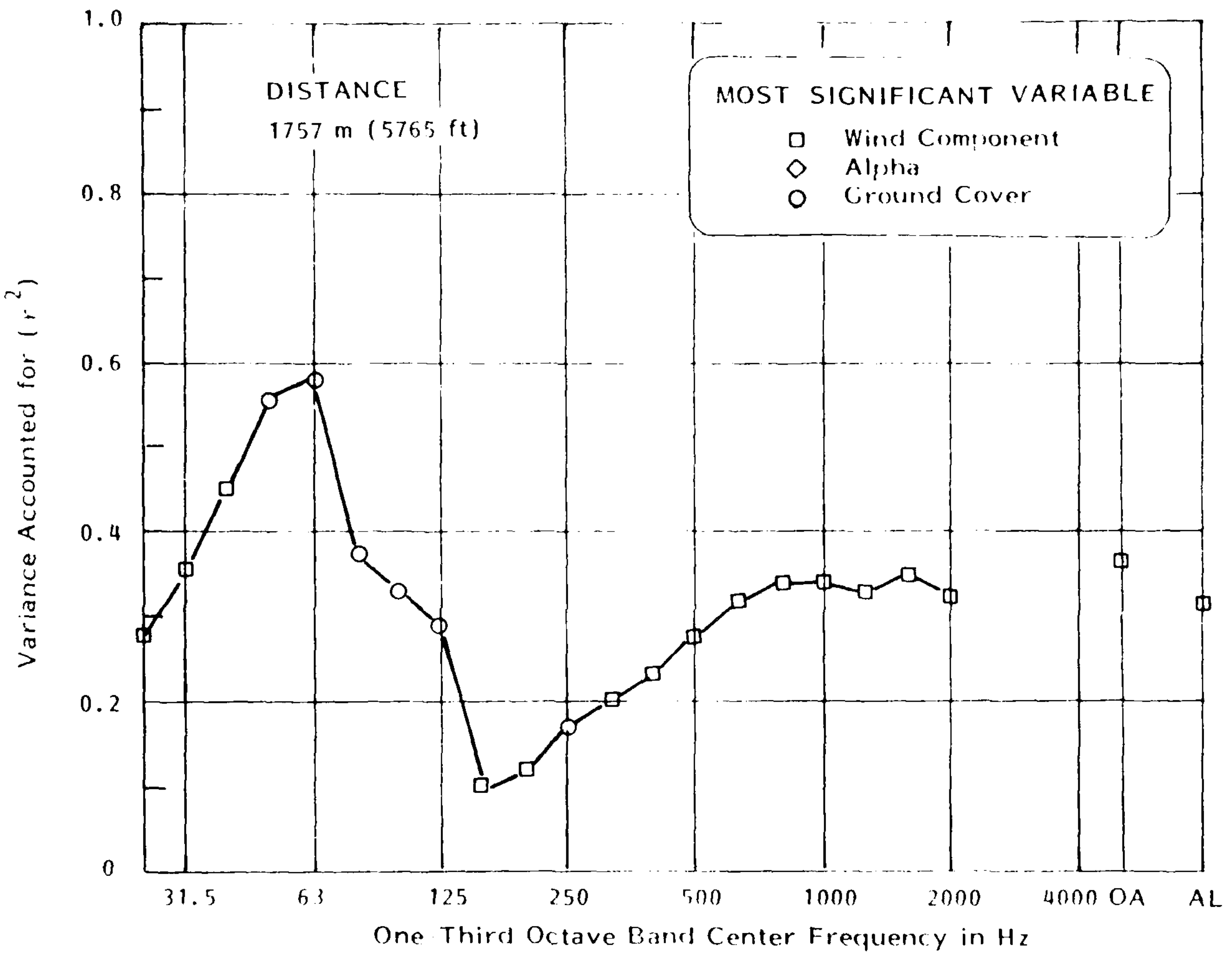

FIGURE 12 F. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER, DISTANCE 1757 m

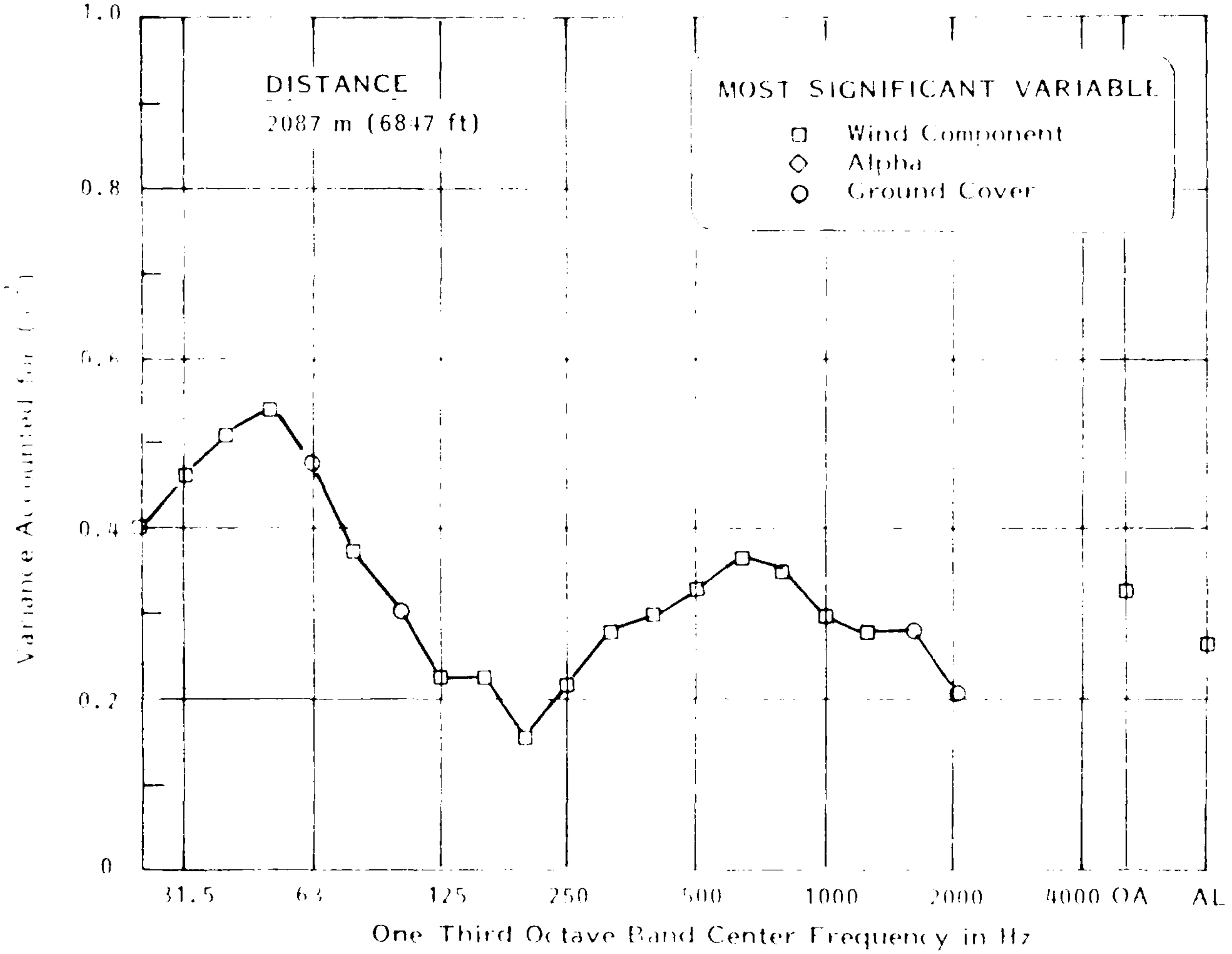

FIGURE 12 G. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER
DISTANCE = 2087 m

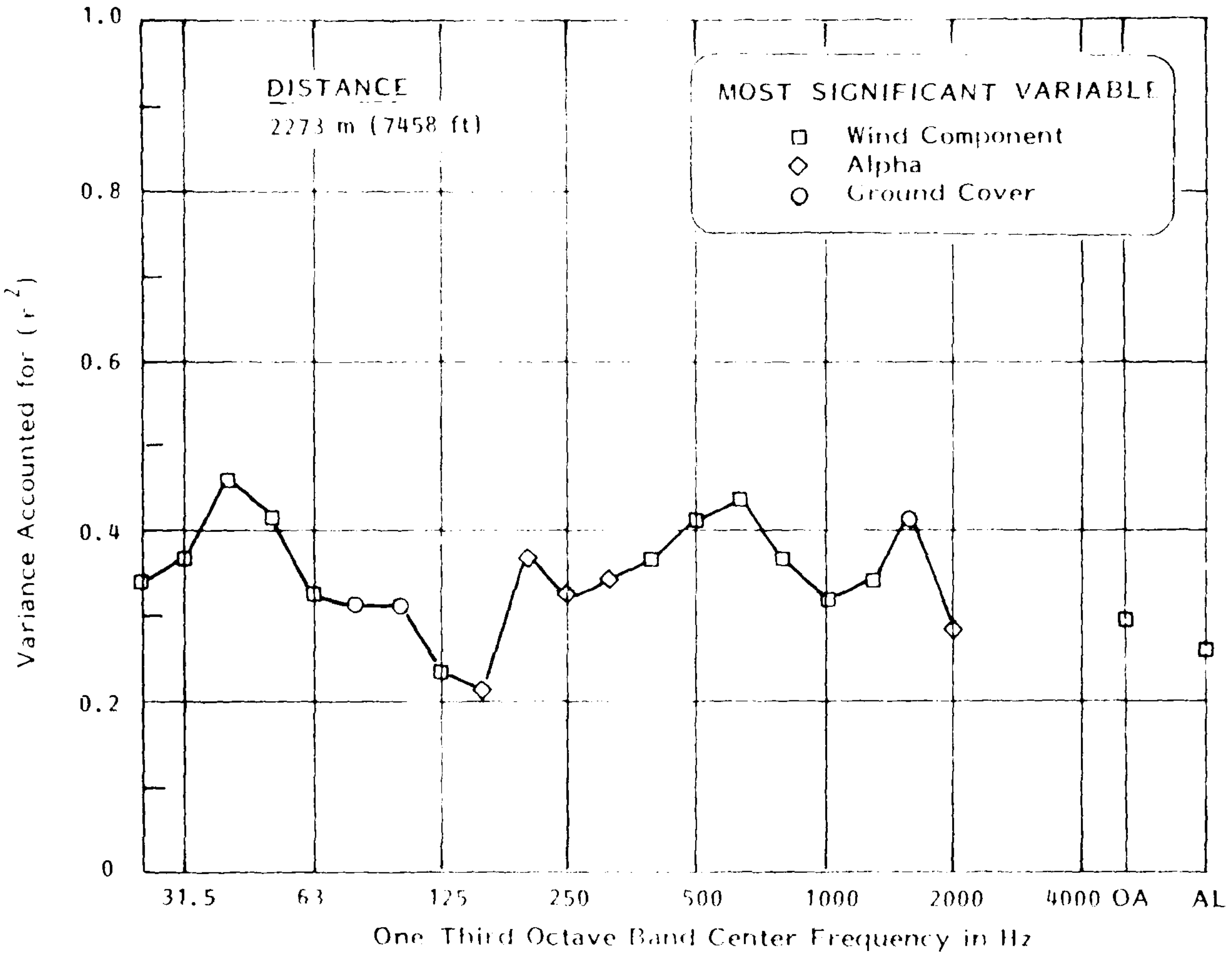

FIGURE 12 H. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER, DISTANCE 2273 m

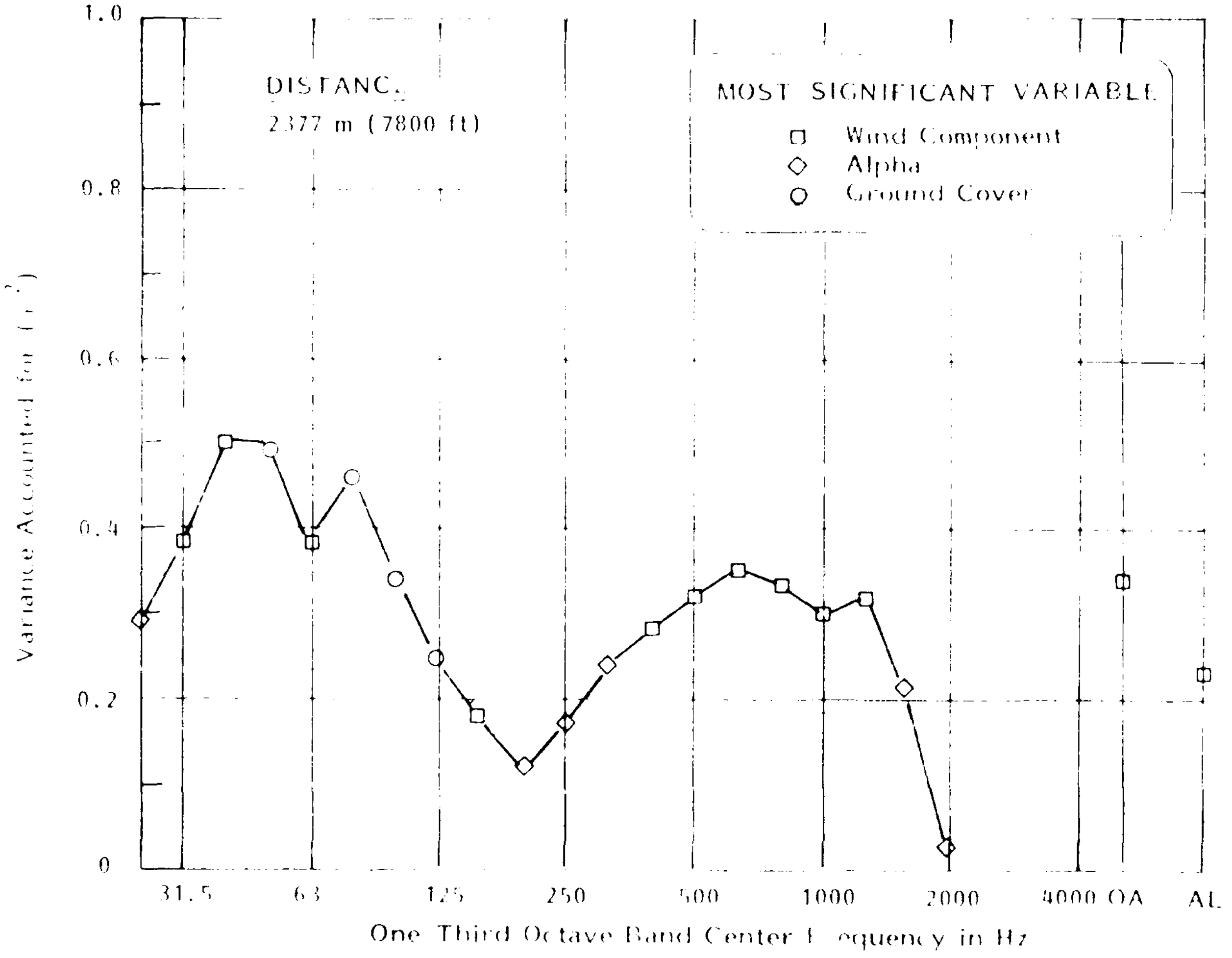

FIGURE 3. 1. VARIANCE IN ESA ACCOUNTED FOR BY WIND COMPONENT, TEMPERATURE GRADIENT AND GROUND COVER DISTANCE [illegible]

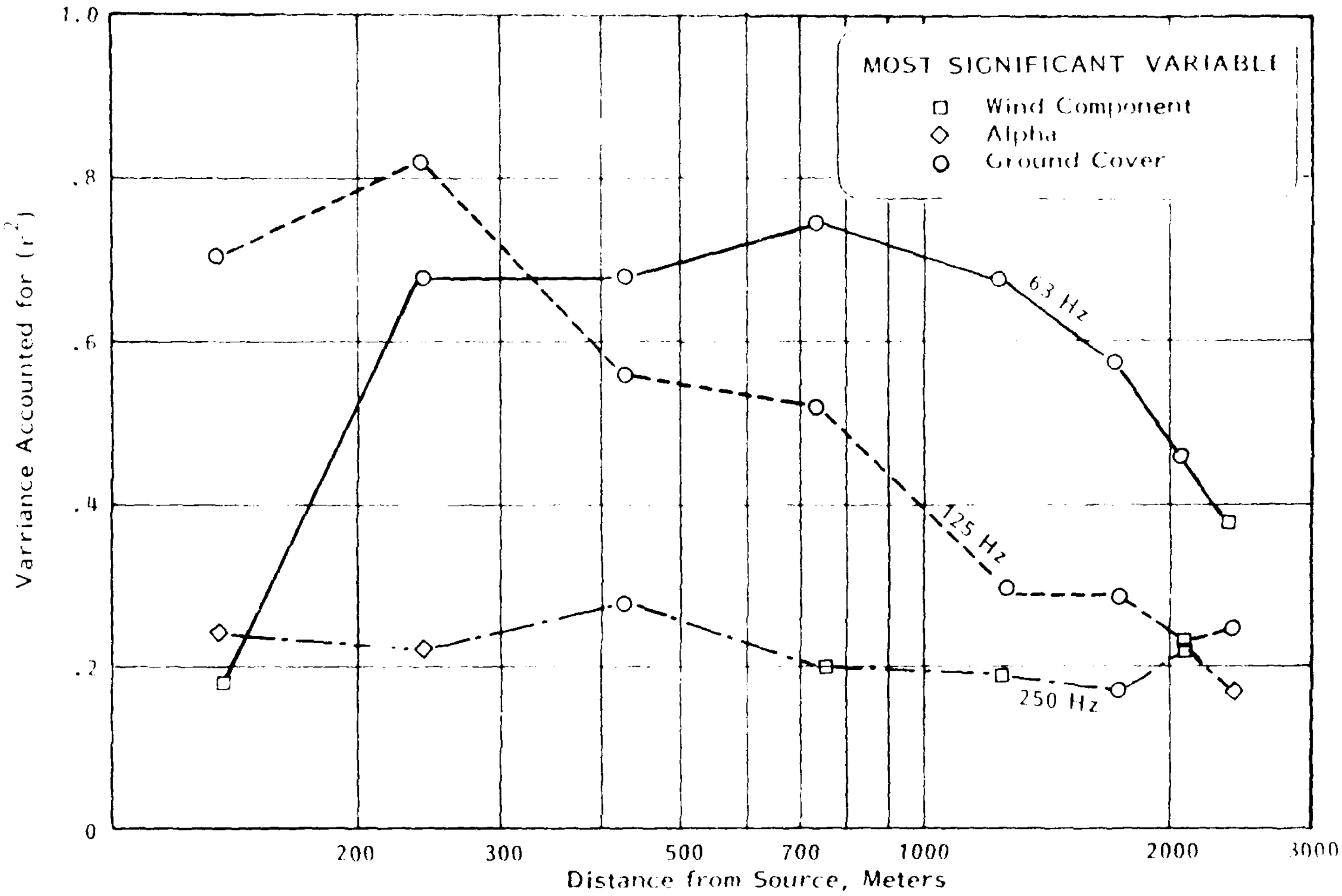

FIGURE 13 A. VARIANCE IN ESA ACCOUNTED FOR AS A FUNCTION OF DISTANCE FROM SOURCE 63, 125 AND 250 Hz ONE THIRD OCTAVE BANDS

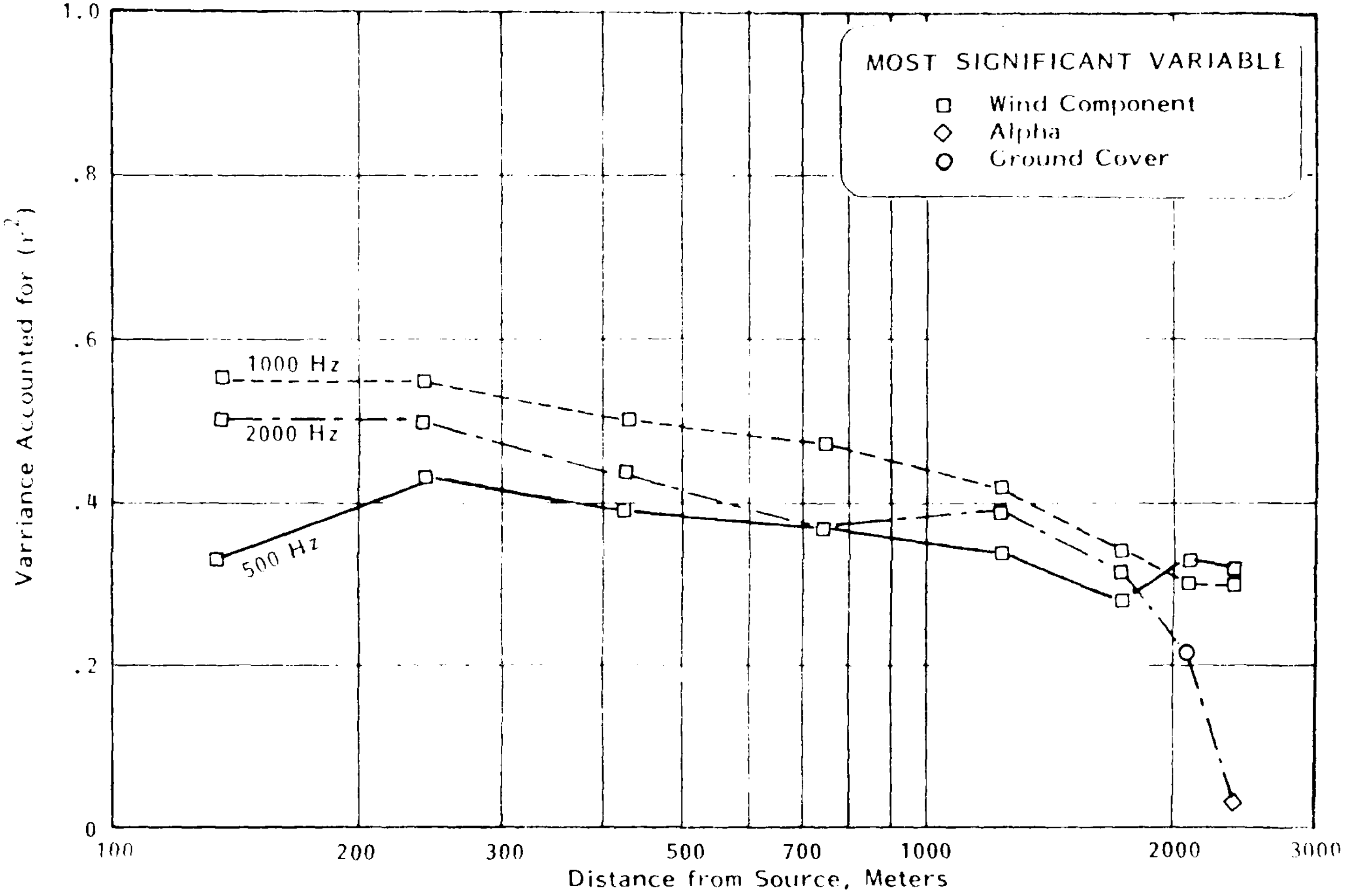

FIGURE 13 B. VARIANCE IN ESA ACCOUNTED FOR AS A FUNCTION OF DISTANCE FROM SOURCE — 500, 1000 AND 2000 Hz ONE THIRD OCTAVE BANDS

A review of Figure 12 will show that the r^2 values generally show two distinct maxima as a function of frequency. The maximum r^2 values for each of these two peaks are tabulated in Table 9, together with the frequency at which the maximum occurs. One r^2 maximum occurs at low frequencies, from a frequency of 160 Hz at the closest distance, shifting to lower frequencies at greater distances, to reach 40 Hz at the greatest distance. There is a secondary higher frequency maximum where r^2 values are less than the first maximum. This secondary maximum occurs at 1250 Hz at close-in distances decreasing to 630 Hz at the greatest distances. The most significant variable at the low frequency peak is the ground cover, at least up to a distance of 1757 meters. For the high frequency maximum, the most significant variable is the wind component.

Inspection of plots of excess attenuation versus wind component values at the higher frequencies suggests that the variation of ESA with wind component is not a simple linear relationship. Further inspection also indicated that the ESA values may be influenced by the array direction (see Figure 1). This influence of array direction may be due to the difference in distances for the reference microphone positions (66 m versus 75 m) combined with the differences in the ground surface between the microphone and the reference position for the two arrays. Thus multiple linear regression analyses introducing the wind component values as squared and cubed functions and the array direction (odd versus even) as independent variables were undertaken.

Introducing the wind component as squared and cubed variables resulted in a modest increase in the r^2 values at frequencies of approximately 250 Hz and higher where the r^2 increases by the order of 10 percent.

The addition of the array direction as a variable generally resulted in modest to sizeable increases in the variance accounted for. Sizeable increases in the variance accounted for were typically in the higher frequencies, most noticeably at 500 Hz.

Table 10 summarizes the results of the analyses with the added variables and shows the r^2 values at octave band intervals from 31 to 2000 Hz for various distances. Shown in the table are the r^2 values for the original set of variables, the results with the wind component squared and cubed added as a variable. The last two columns in the table show the percentage increase observed in the r^2 values with the two added sets of variables.

Figure 14 compares the r^2 values for the 500 Hz one-third octave band with the wind component squared and cubed, and array direction 03 and 04 as independent variables. Adding the array direction as a variable was generally most significant for the 500 Hz band.

TABLE 10. COMPARISONS OF REGRESSION RESULTS FOR DIFFERENT SETS OF INDEPENDENT VARIABLES

Distance	Frequency (Hz)	Variance Accounted For (r^2) Variable Set (1)	Variable Set (2)	Variable Set (3)	Percent Increase in r^2 re Set (1) Set (2)	Set (3)
1.4 m (4.6 ft)	31	0.1110	0.1110	0.4035	0	65.[illegible]
	63	0.1[illegible]	0.1574	0.3347	5.8	32.4
	125	0.7[illegible]	0.7277	0.7632	2.1	9.[illegible]
	250	0.24[illegible]	0.2422	0.2686	0	11.[illegible]
	[illegible]	0.234[illegible]	0.2340	0.6092	0	79.7
	1000	0.5[illegible]48	0.5[illegible]48	0.6115	0	10.[illegible]
	2000	0.5[illegible]	0.5384	0.5745	7.1	14.[illegible]
[illegible] m ([illegible] ft)	31	0.24[illegible]	0.2426	0.2884	0	18.[illegible]
	63	0.6860	0.6860	0.6860	0	0
	125	0.8[illegible]02	0.8[illegible]02	0.8293	0	1.1
	250	0.2[illegible]9	0.2[illegible]9	0.2677	0	17.[illegible]
	500	0.4377	0.4460	0.6187	1.9	41.4
	1000	0.5525	0.5723	0.6800	3.6	15.[illegible]
	2000	0.5047	0.5436	0.6035	7.5	1[illegible]
4.2 m (14.[illegible] ft)	31	0.4554	0.4619	0.4844	1.4	6.4
	63	0.6852	0.6924	0.7137	1.1	4.[illegible]
	125	0.5657	0.5867	0.5867	3.7	3.7
	250	0.2816	0.3186	0.3312	13.1	17.[illegible]
	500	0.3933	0.4459	0.5814	13.4	47.8
	1000	0.5[illegible]	0.5331	[illegible]	5.[illegible]	16.[illegible]
	[illegible]	0.4[illegible]	0.47[illegible]	[illegible]	1[illegible]	[illegible]

TABLE 10. COMPARISONS OF REGRESSION RESULTS FOR DIFFERENT SETS OF INDEPENDENT VARIABLES (CONTINUED)

Distance	Frequency Hz	Variance Accounted For (r^2) Variable Set(1)	Variable Set(2)	Variable Set(3)	Percent Increase in r^2 re Set (1) Set (2)	Set (3)
753 m 2471 ft	31	0.4586	0.4661	0.5415	1.6	18.1
	63	0.7514	0.7514	0.7514	0	0
	125	0.5242	0.5242	0.5242	0	0
	250	0.2076	0.2664	0.3991	28.4	92.2
	500	0.3797	0.4349	0.5928	14.5	56.1
	1000	0.4754	0.5115	0.5997	7.6	26.1
	2000	0.3746	0.4063	0.5372	8.5	43.4
1255 m 4118 ft	31	0.4694	0.4788	0.4869	1.4	3.7
	63	0.6844	0.6844	0.6844	0	0
	125	0.2907	0.2907	0.3530	0	21.4
	250	0.1941	0.2275	0.2544	17.2	31.1
	500	0.3435	0.3881	0.4521	13.0	31.6
	1000	0.4113	0.4540	0.4939	10.4	20.1
	2000	0.3917	0.4247	0.4639	8.4	18.4
1757 m 5764 ft	31	0.3529	0.3529	0.3529	0	0
	63	0.5895	0.6036	0.6036	2.4	2.4
	125	0.2969	0.3339	0.3627	12.5	22.2
	250	0.1766	0.1903	0.2827	7.8	60.1
	500	0.2871	0.3190	0.3751	11.1	30.7
	1000	0.3467	0.3745	[illegible]	8.1	34.[illegible]
	2000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 10. COMPARISONS OF REGRESSION RESULTS FOR DIFFERENT SETS OF INDEPENDENT VARIABLES (CONTINUED)

Distance	Frequency Hz	Variance Accounted For (r^2) Variable Set(1)	Variable Set(2)	Variable Set(3)	Percent Increase in r^2 re Set (1) Set (2)	Set (3)
2057 m (6747 ft)	31	0.4698	-	0.4971	-	5.8
	63	0.4859	-	0.5267	-	8.4
	125	0.2393	-	0.3364	-	40.6
	250	0.2245	-	0.3982	-	77.4
	500	0.3391	-	0.4830	-	42.4
	1000	0.3002	-	0.4157	-	38.5
	2000	0.2176	-	0.2914	-	33.9
2377 m (7800 ft)	31	0.3866	0.4057	0.4057	4.9	4.9
	63	0.3890	0.4598	0.4598	18.2	18.2
	125	0.2556	0.2944	0.2944	15.2	15.2
	250	0.1769	0.1769	0.2890	0	63.4
	500	0.3261	0.3409	0.4284	4.5	31.4
	1000	0.3046	0.3487	0.4685	14.5	53.8
	2000	-	0.0300	0.0782	-	-

(1) Independent variables: wind component, alpha (temperature gradient) and ground surface conditions (grass or snow.

(2) Independent variables: as (1) plus (wind component)^2 and (wind component)^3.

(3) Independent variables: as (2) plus array (see Figure 1).

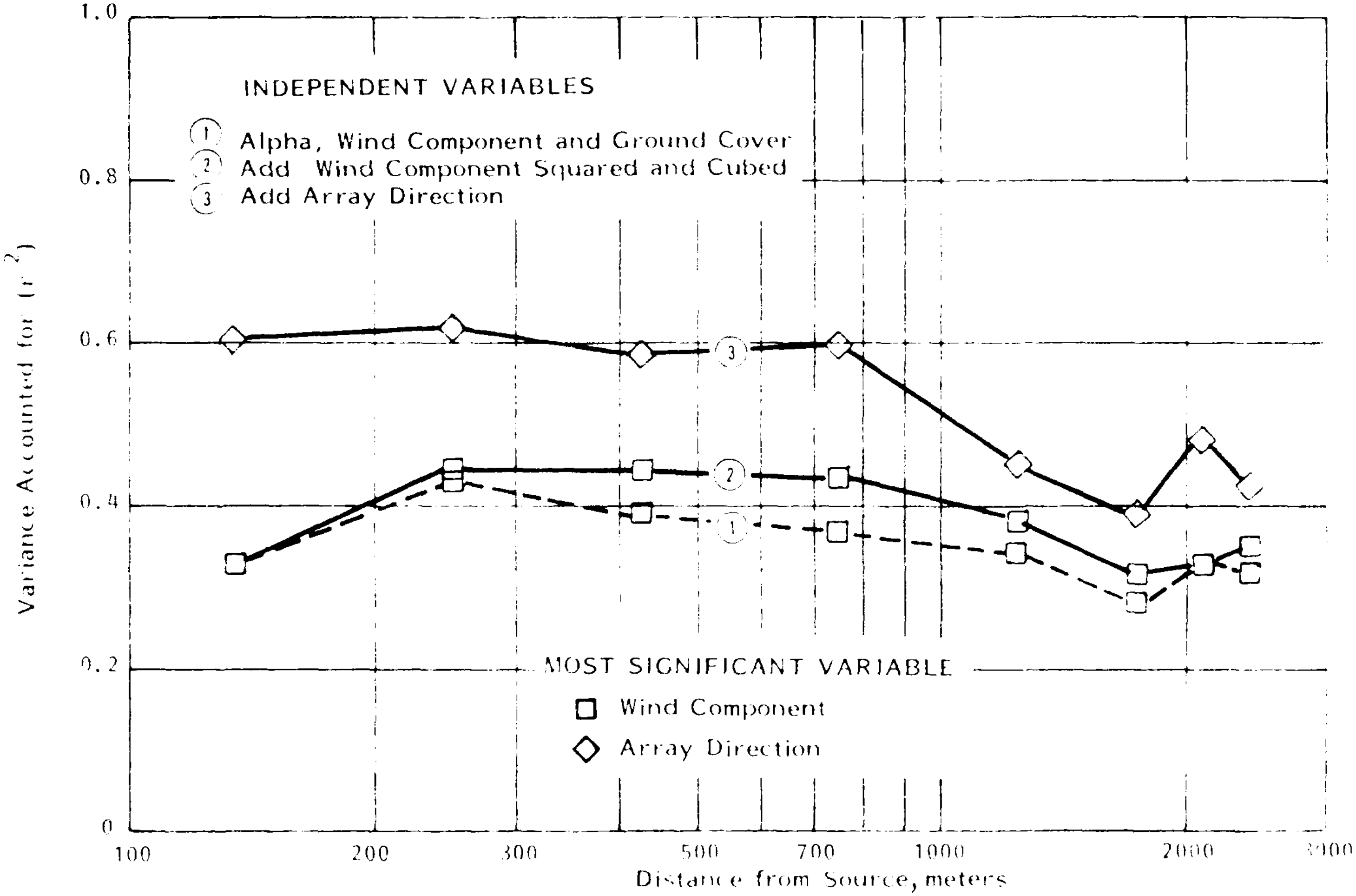

FIGURE 18. VARIANCE IN ESA ACCOUNTED FOR AS A FUNCTION OF DISTANCE 50 Hz ONE THIRD OCTAVE FREQUENCY BAND EXPANDED NUMBER OF INDEPENDENT VARIABLES

4.0 ESA VARIATIONS WITH GROUND SURFACE CONDITIONS, WIND COMPONENT AND TEMPERATURE GRADIENT

4.1 ESA Variations with Ground Surface Conditions

The ground surface conditions may be broadly categorized as grass covered (dry, wet, dew or frost) and snow covered (variable depths). The influence of ground cover on ESA is generally most apparent at the frequency range below about 1000 Hz and differences in ESA due to ground cover may be most easily identified under near neutral temperature gradients and low wind component conditions.

This section presents a comparison of the ESA values for such weather conditions. Thus, for data obtained under near neutral temperature gradients (-0.2 m/s < alpha < 0.2 m/s) and low wind component conditions (-1.5 m/s < wind component < 1.5 m/s), the data were divided into groups -- grass cover (a total of 94 cases) or snow cover (33 cases). Average ESA values were then calculated for the two groups, with results presented in Figures 15 and 16.

Figures 15-A through 15-H show the average ESA values for snow and grass cover as a function of frequency for eight distances. Figures 16-A through 16-F show the average ESA values for the grass and snow cover as a function of distance for one-third bands at octave intervals from 63 Hz to 2000 Hz and for the A-level. You will note from the figures that with the snow cover, the maximum ESA values shift to a lower frequency resulting in generally greater attenuations in the frequency range below 200 or 250 Hz. The snow cover results in lower values of excess attenuation typically at the higher frequencies, above about 250 Hz. Figure 16 indicates that the difference in ESA values for the snow

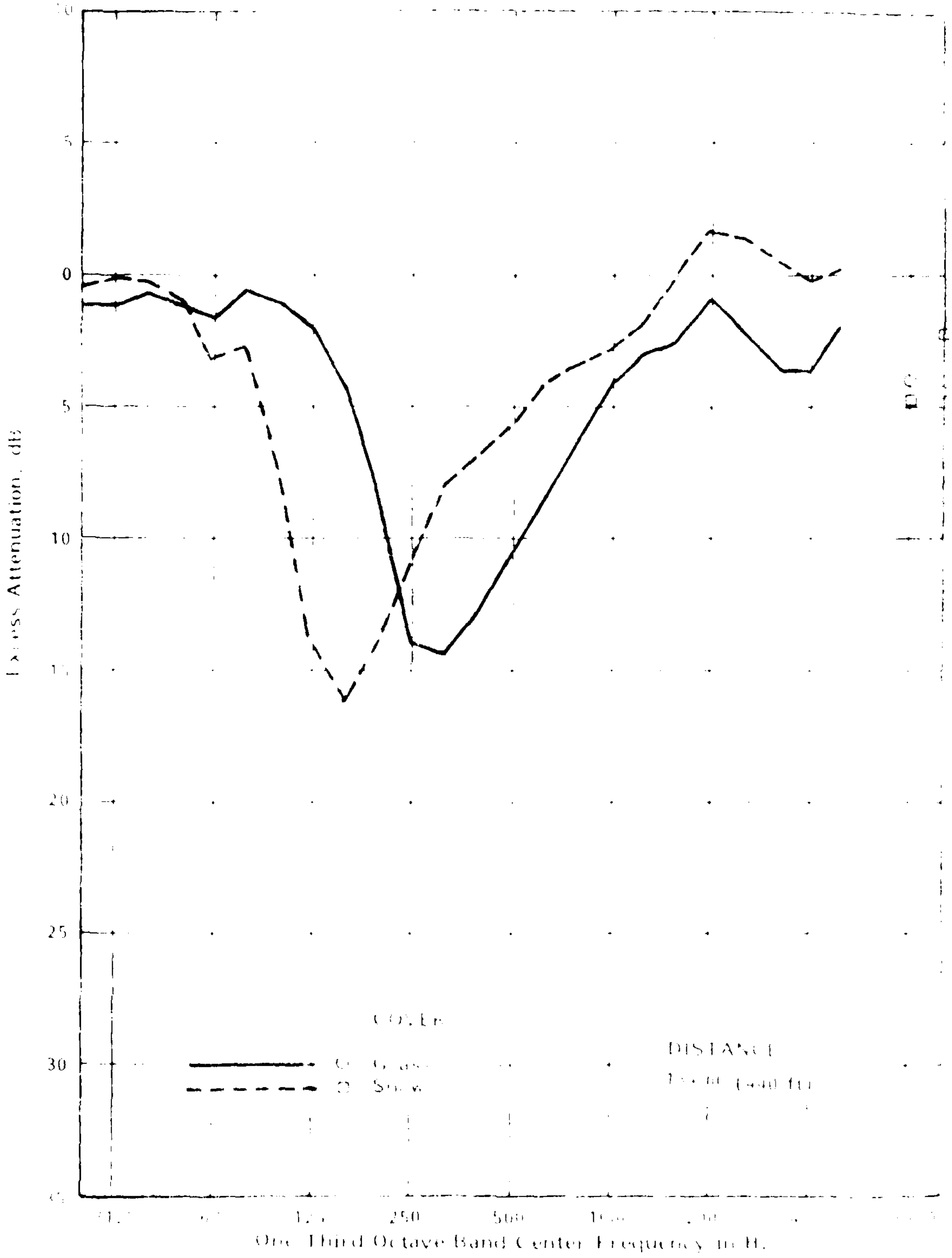

FIGURE 15 A AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW COVER UNDER LOW WIND AND NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS

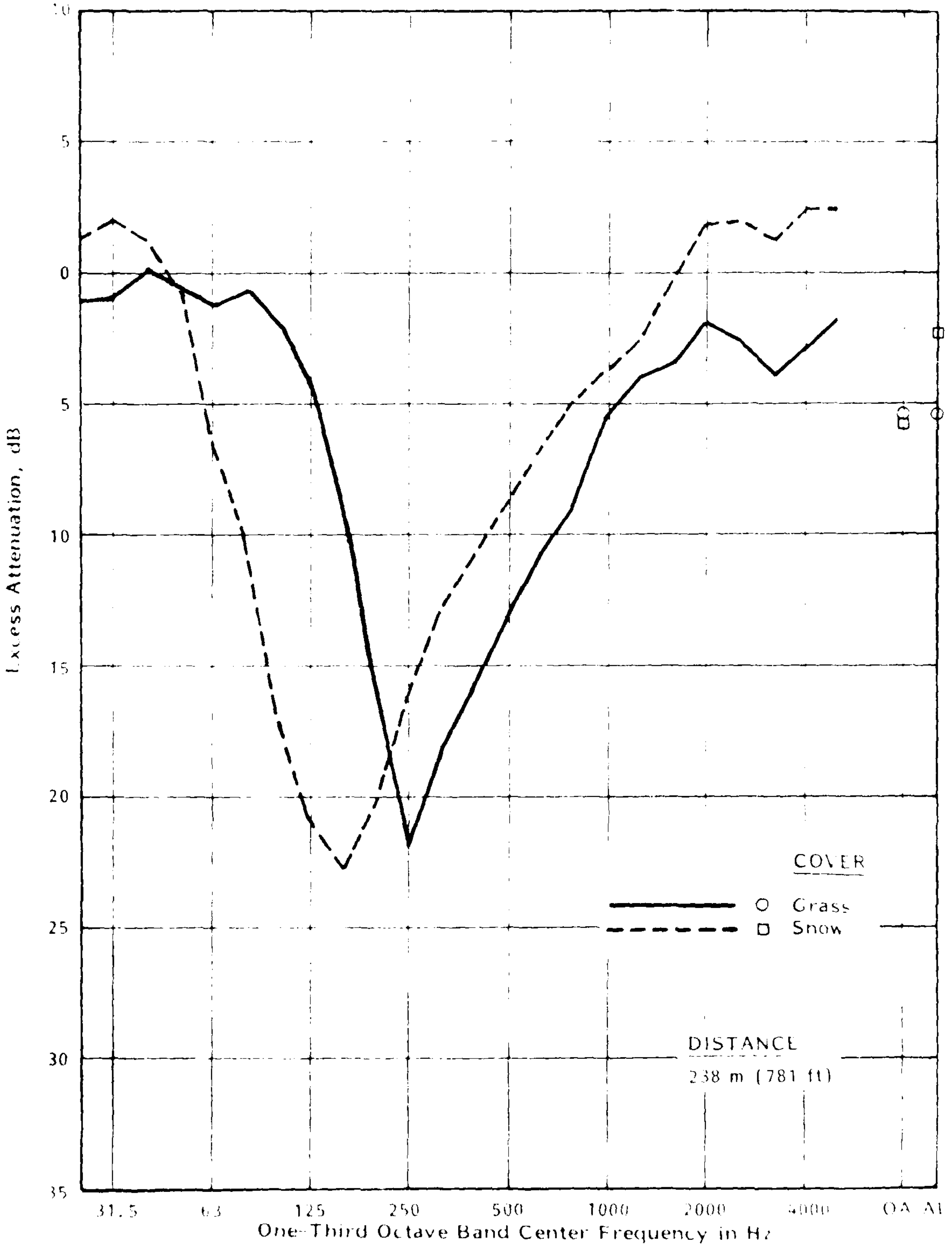

FIGURE 15 B. AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW COVER UNDER LOW WIND AND NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS

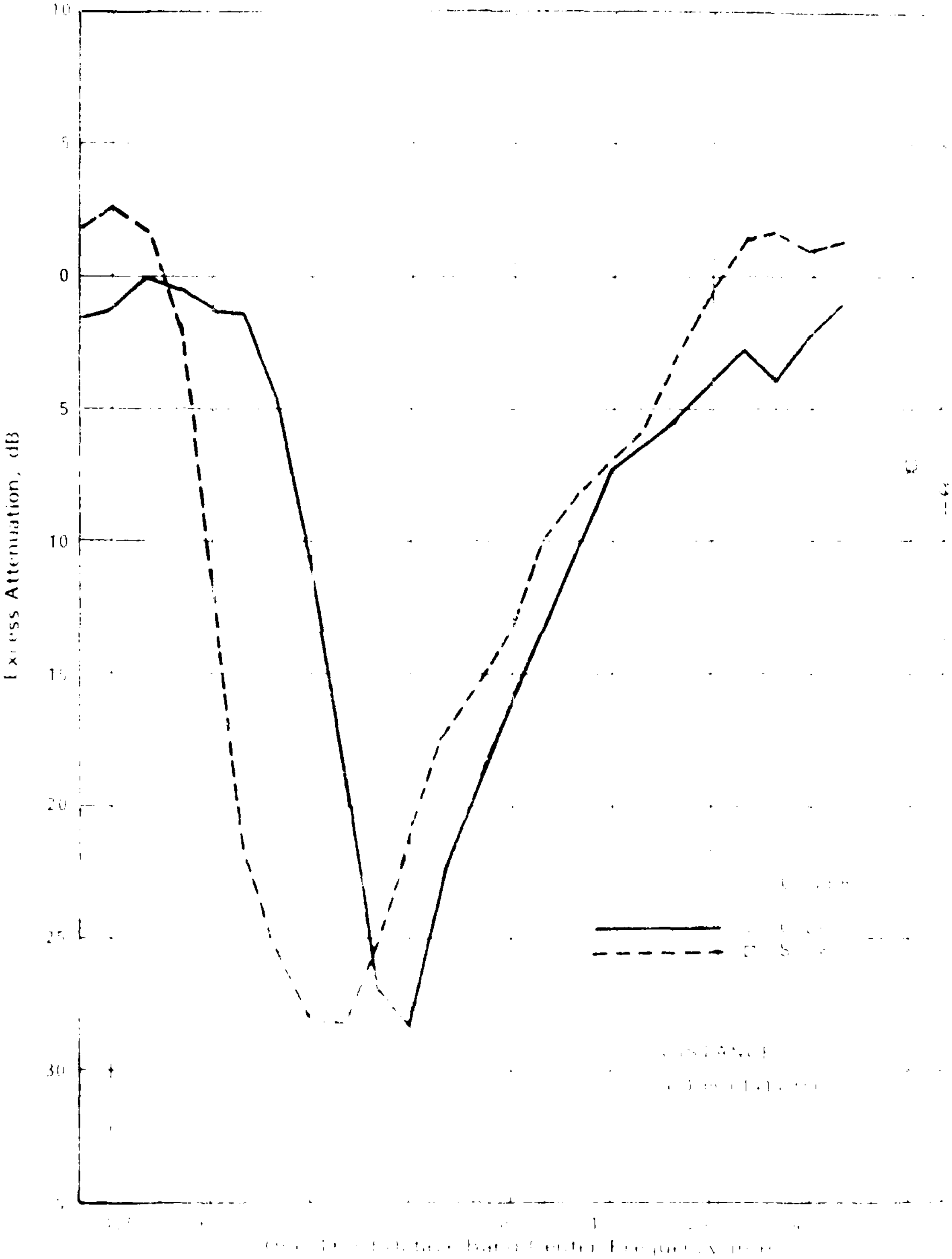

FIGURE [illegible] AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW COVER UNDER DOWNWIND AND NEAR NEUTRAL TEMPERATURE [illegible] CONDITIONS

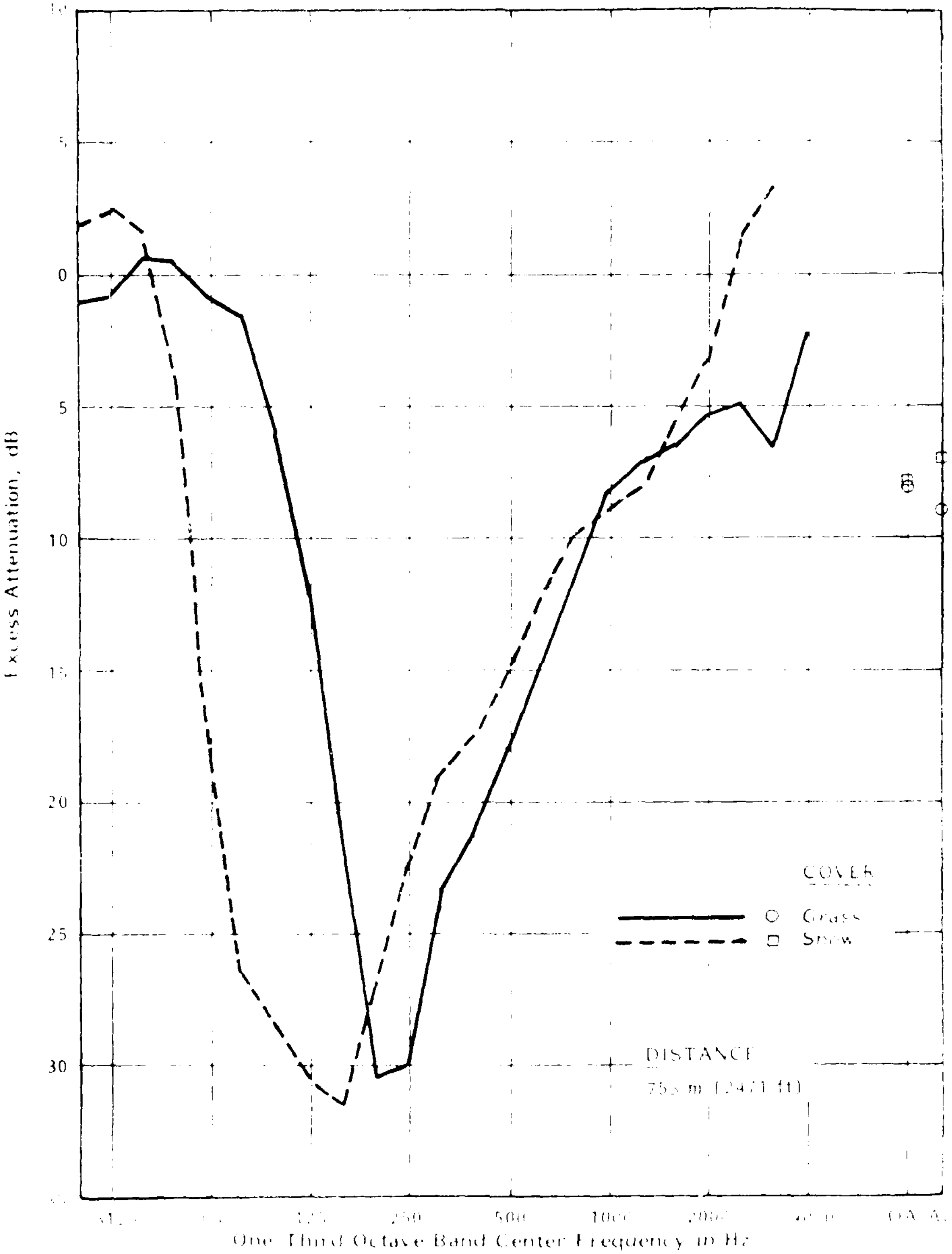

FIGURE [illegible] AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW COVER UNDER LOW WIND AND NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS

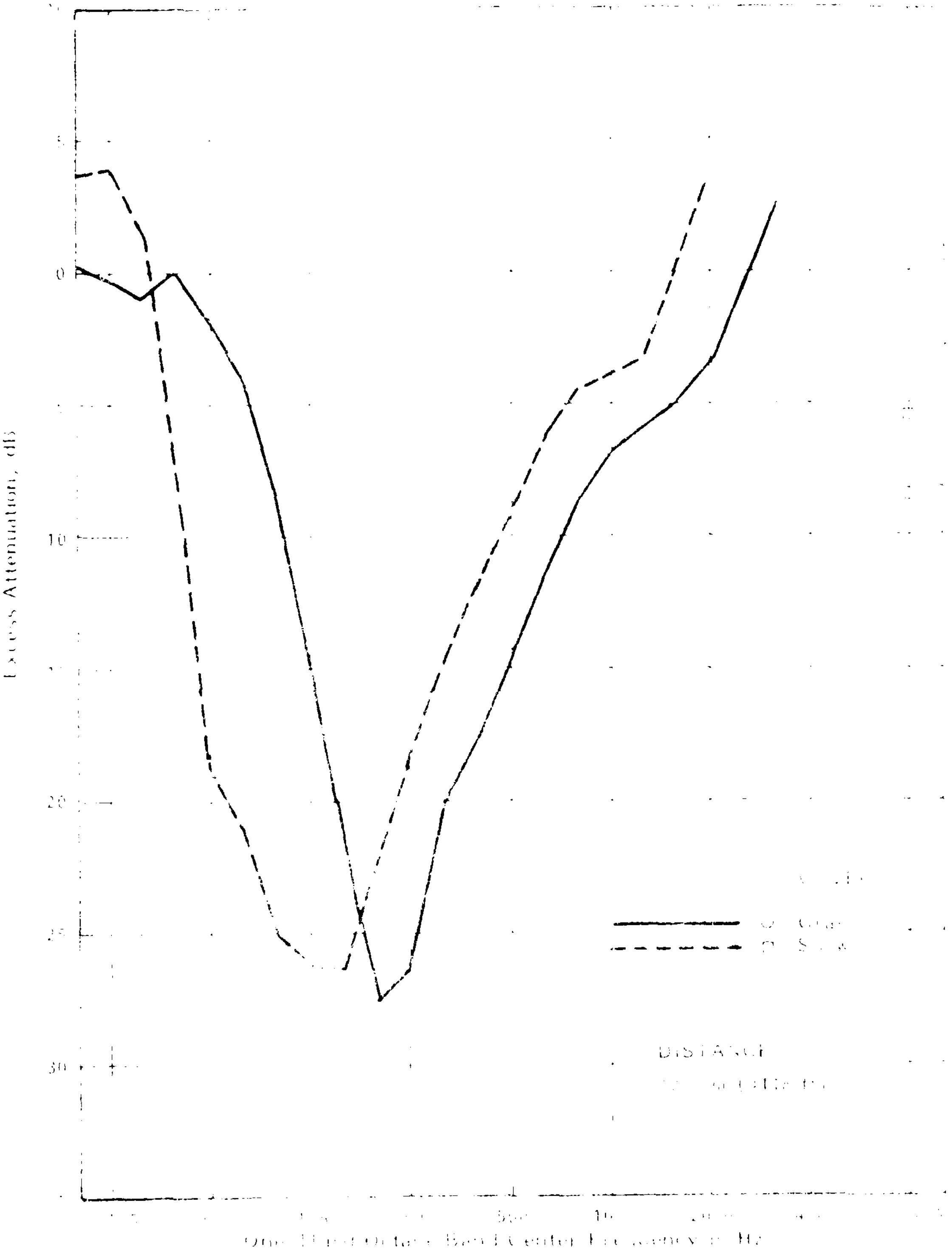

FIGURE [illegible] AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW [illegible] UNDER LOW WIND AND NEAR NEUTRAL TEMPERATURE [illegible] [illegible]

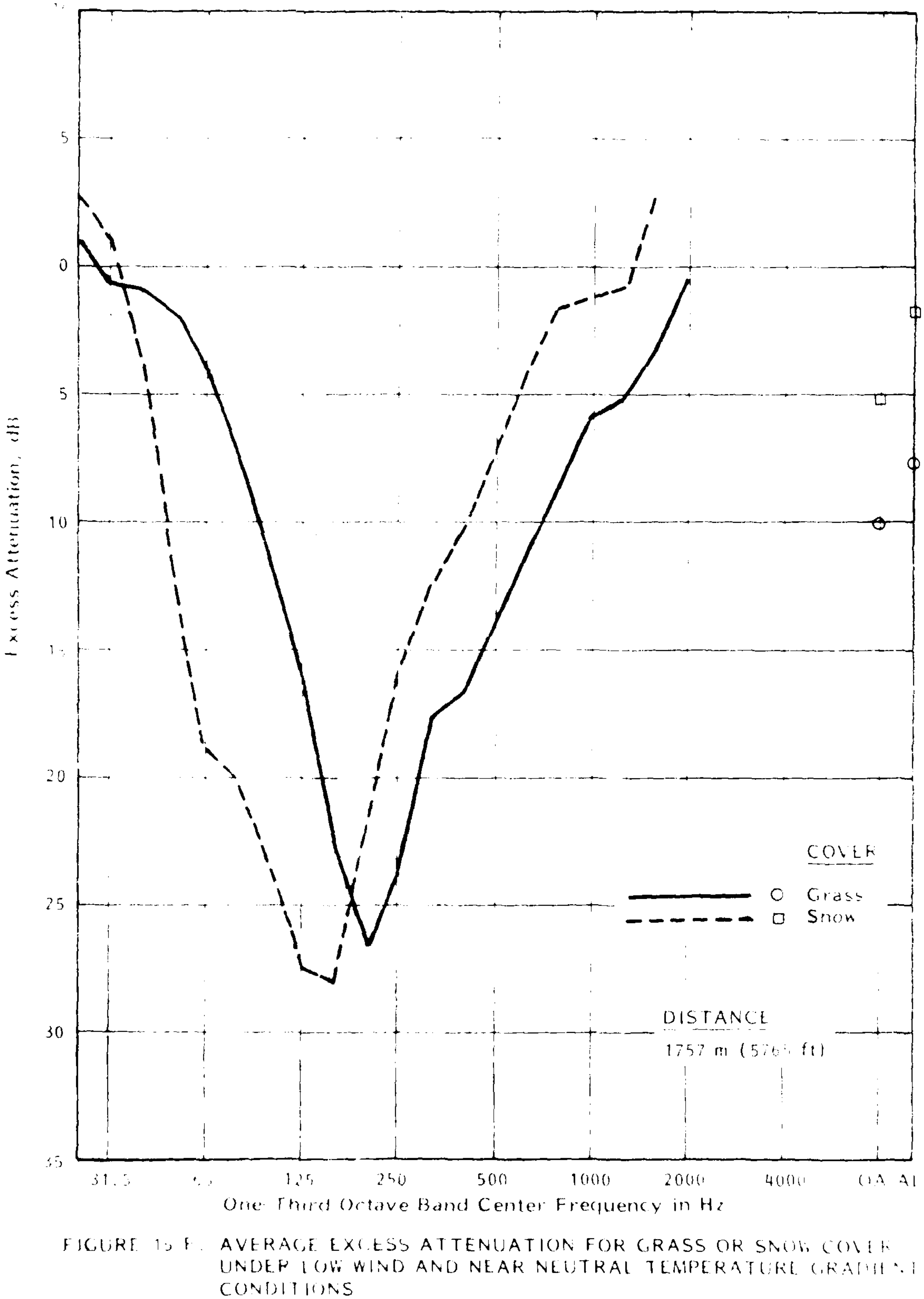

FIGURE 15 F. AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW COVER UNDER LOW WIND AND NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS

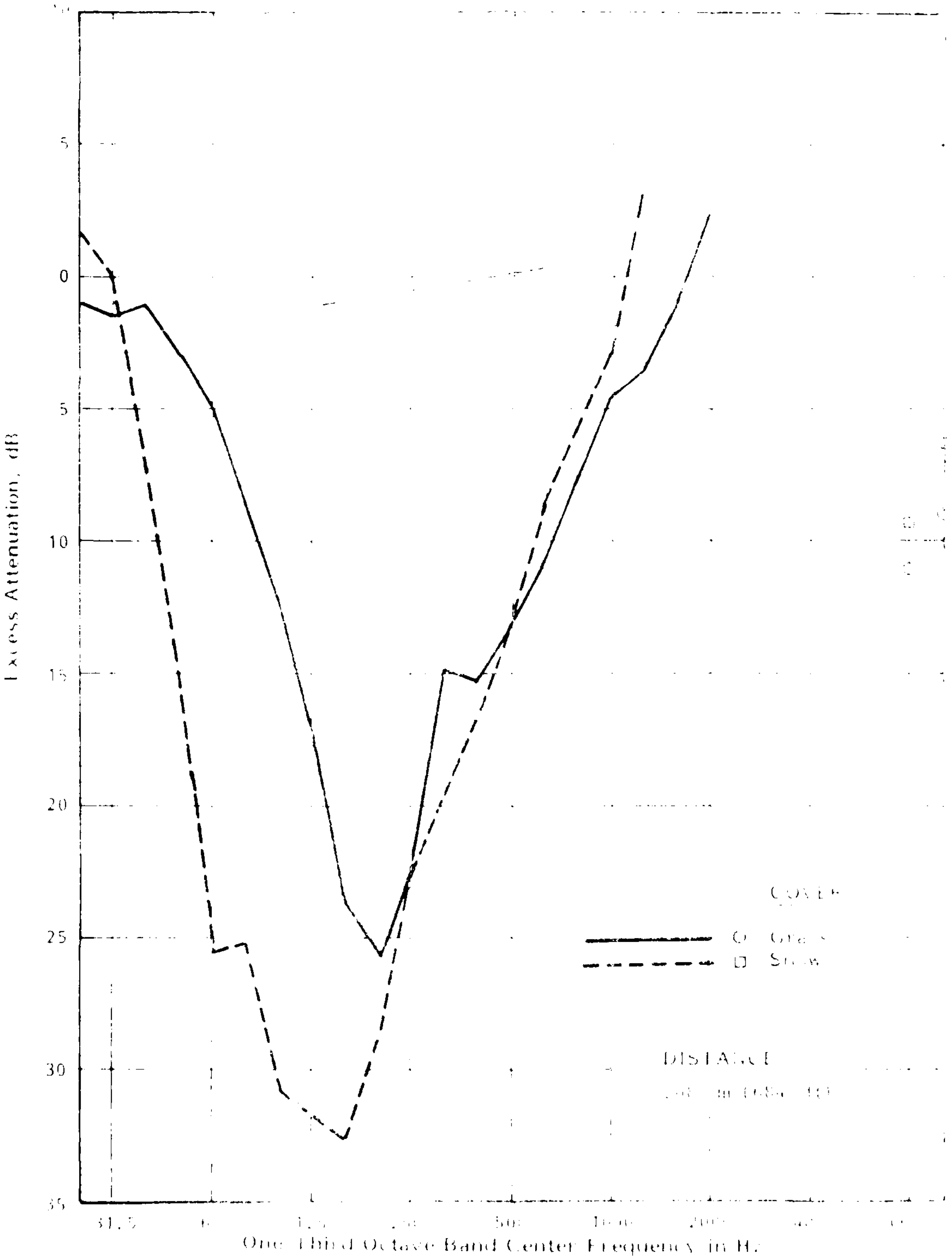

FIGURE 1[illegible] AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW COVER UNDER LOW WIND AND NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS

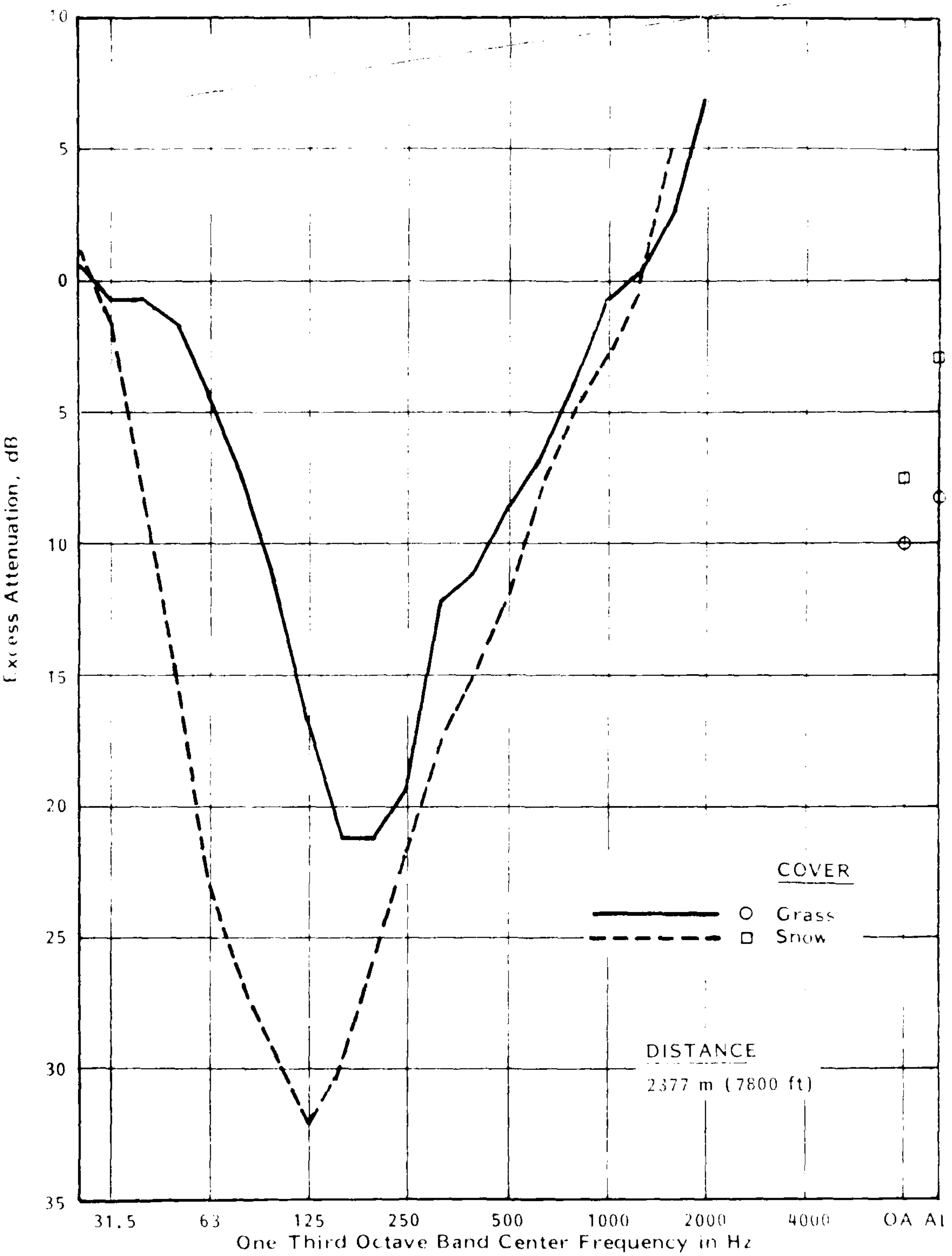

FIGURE 15 H. AVERAGE EXCESS ATTENUATION FOR GRASS OR SNOW COVER UNDER LOW WIND AND NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS

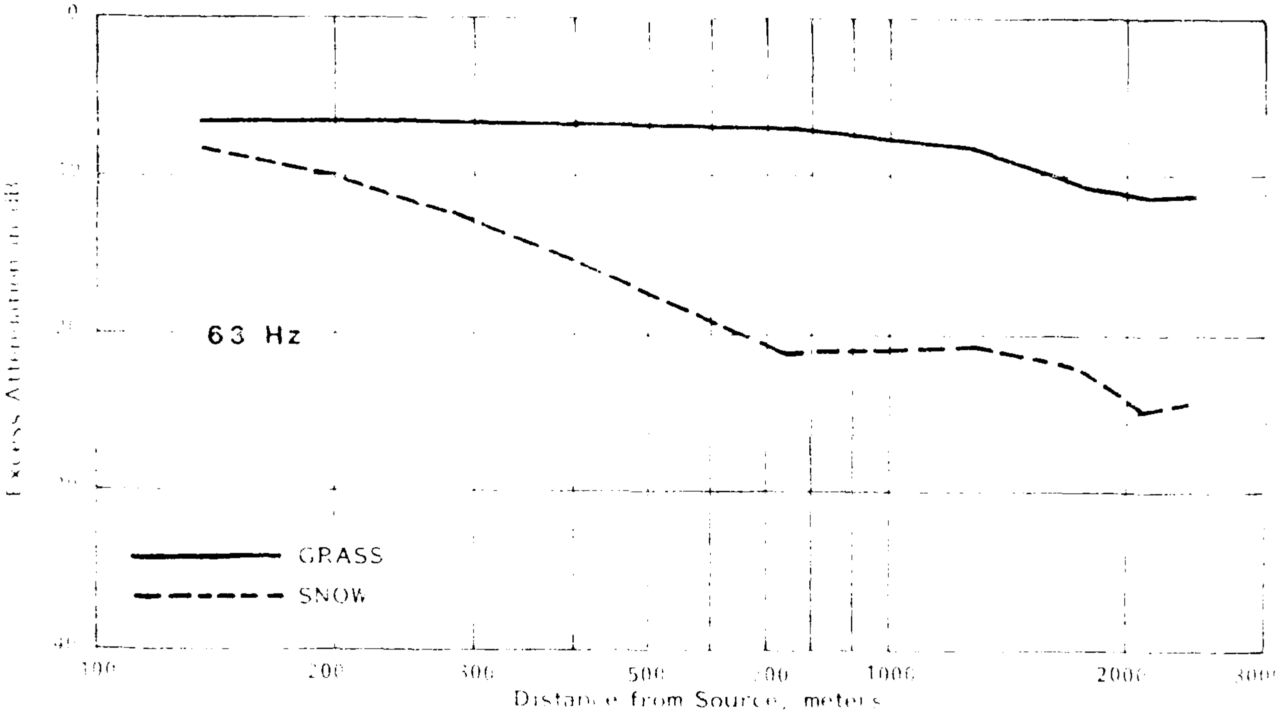

FIGURE 16 A. AVERAGE EXCESS ATTENUATION VARIATION WITH DISTANCE FOR GRASS OR SNOW COVER UNDER LOW WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT CONDITIONS

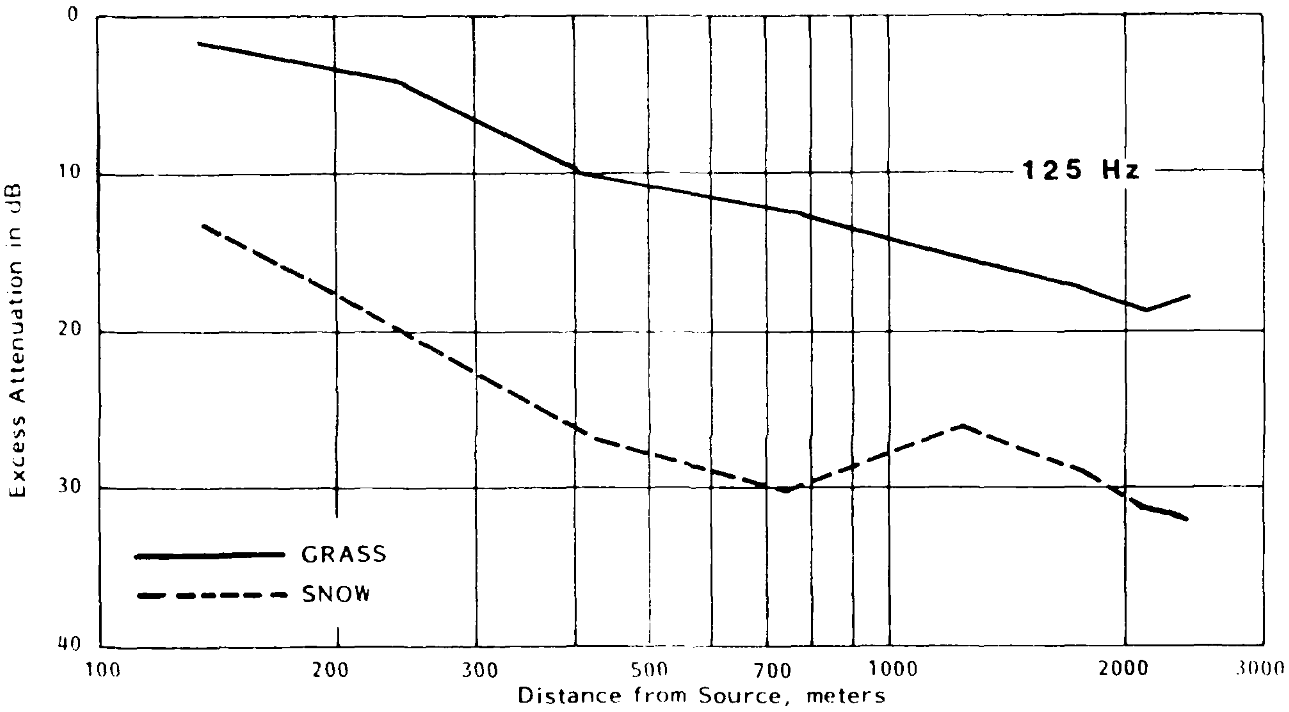

FIGURE 16 B. AVERAGE EXCESS ATTENUATION VARIATION WITH DISTANCE FOR GRASS OR SNOW COVER UNDER LOW WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT CONDITIONS

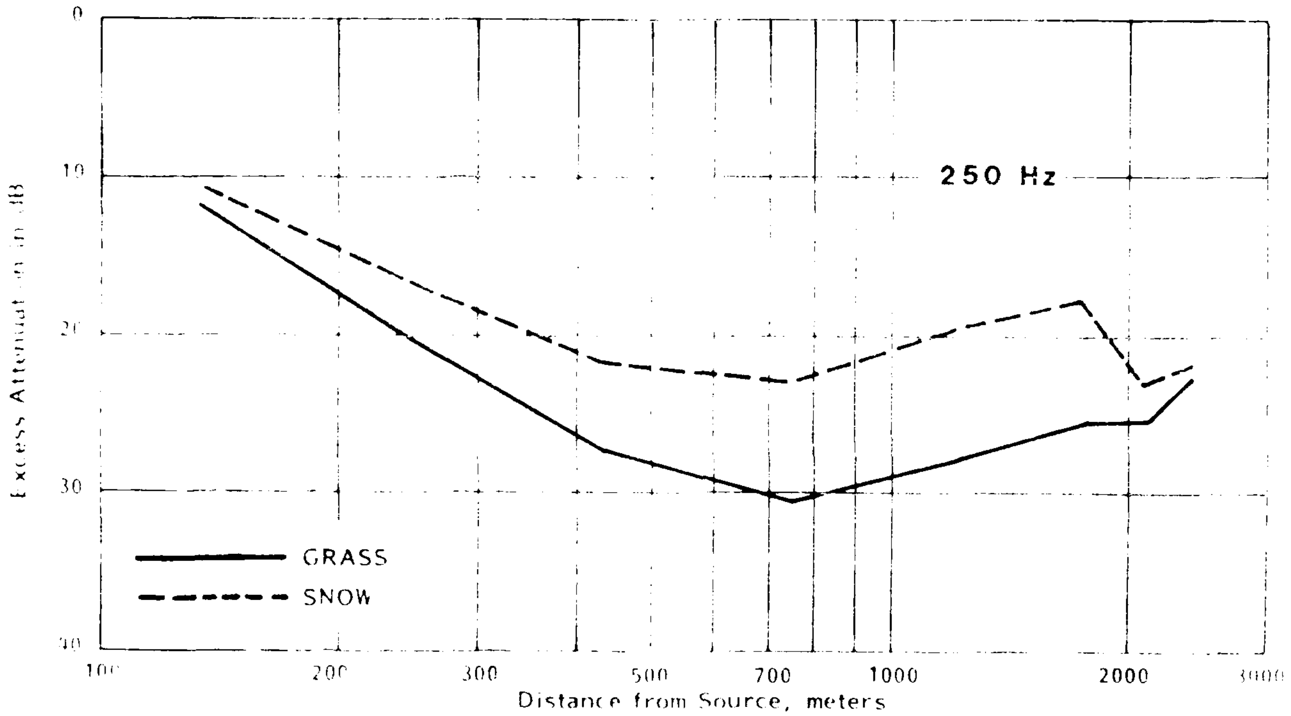

FIGURE 16 C. AVERAGE EXCESS ATTENUATION VARIATION WITH DISTANCE FOR GRASS OR SNOW COVER UNDER LOW WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT CONDITIONS

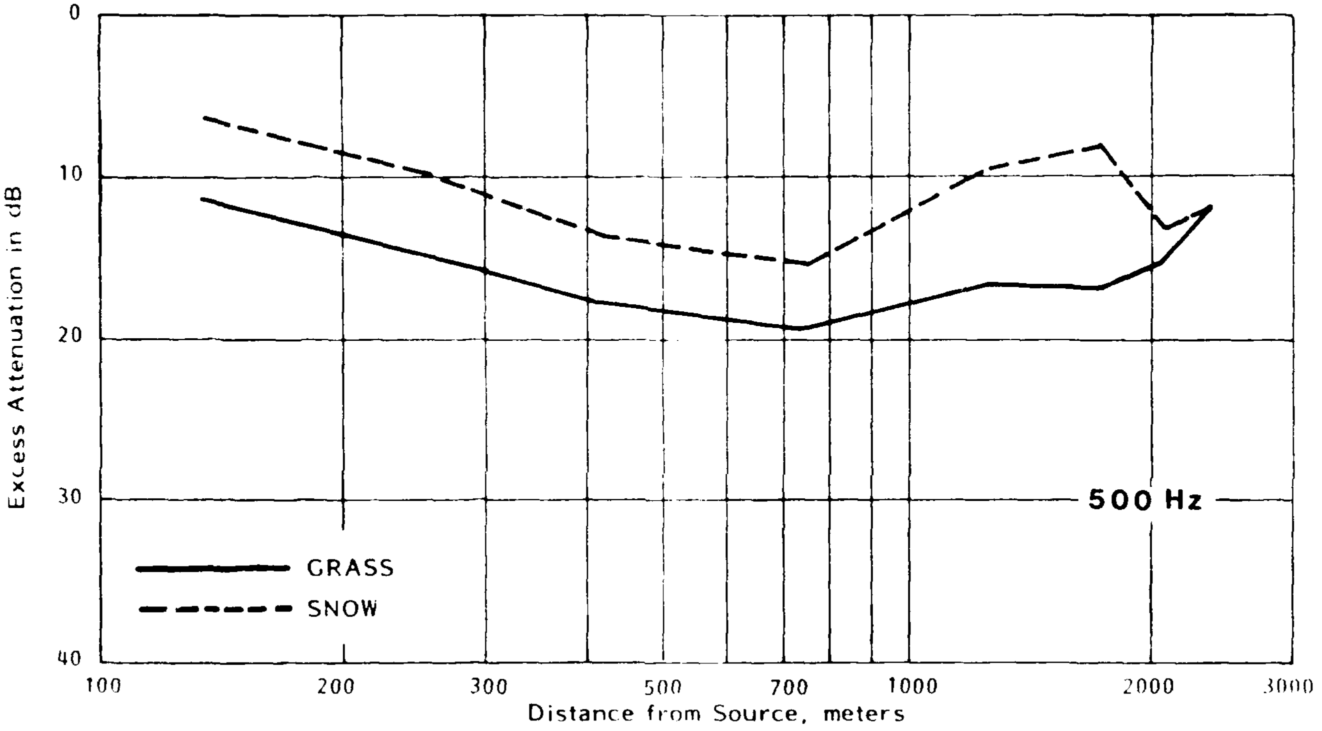

FIGURE 16 D. AVERAGE EXCESS ATTENUATION VARIATION WITH DISTANCE FOR GRASS OR SNOW COVER UNDER LOW WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT CONDITIONS

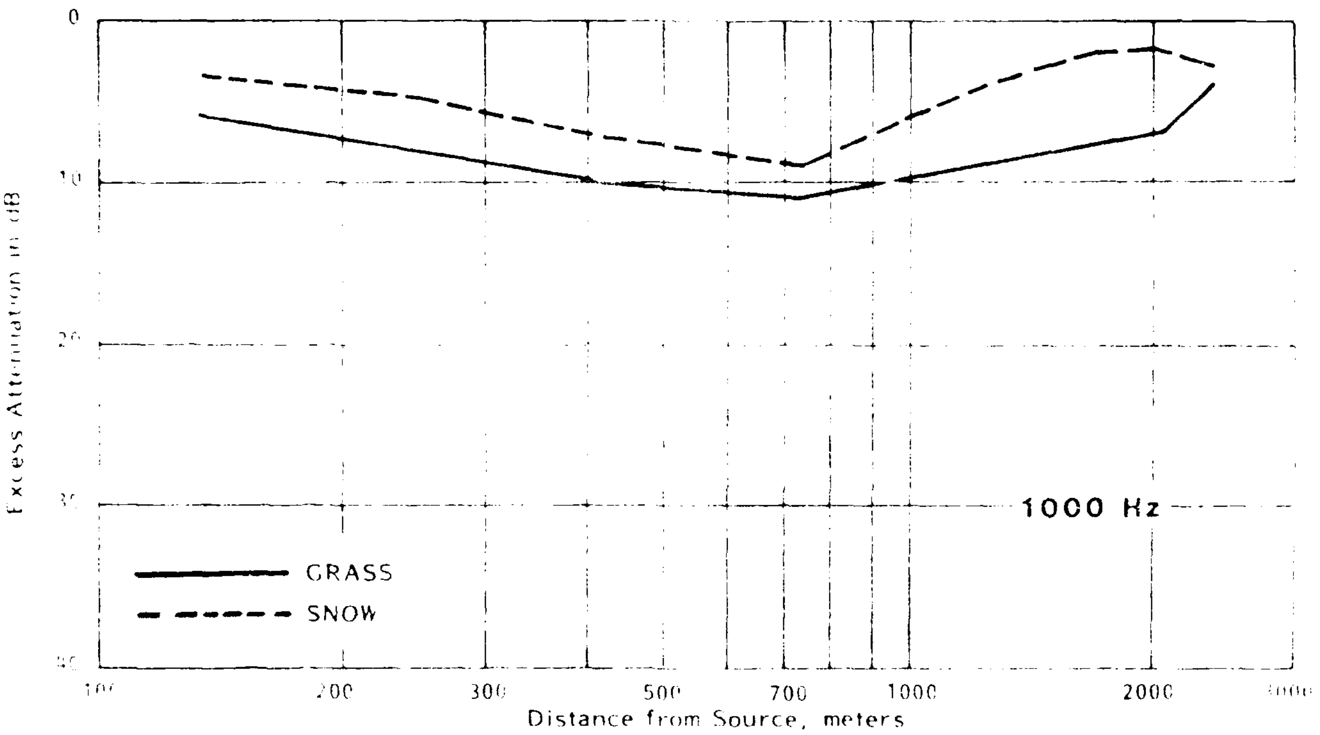

FIGURE 16 E. AVERAGE EXCESS ATTENUATION VARIATION WITH DISTANCE FOR GRASS OR SNOW COVER UNDER LOW WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT CONDITIONS

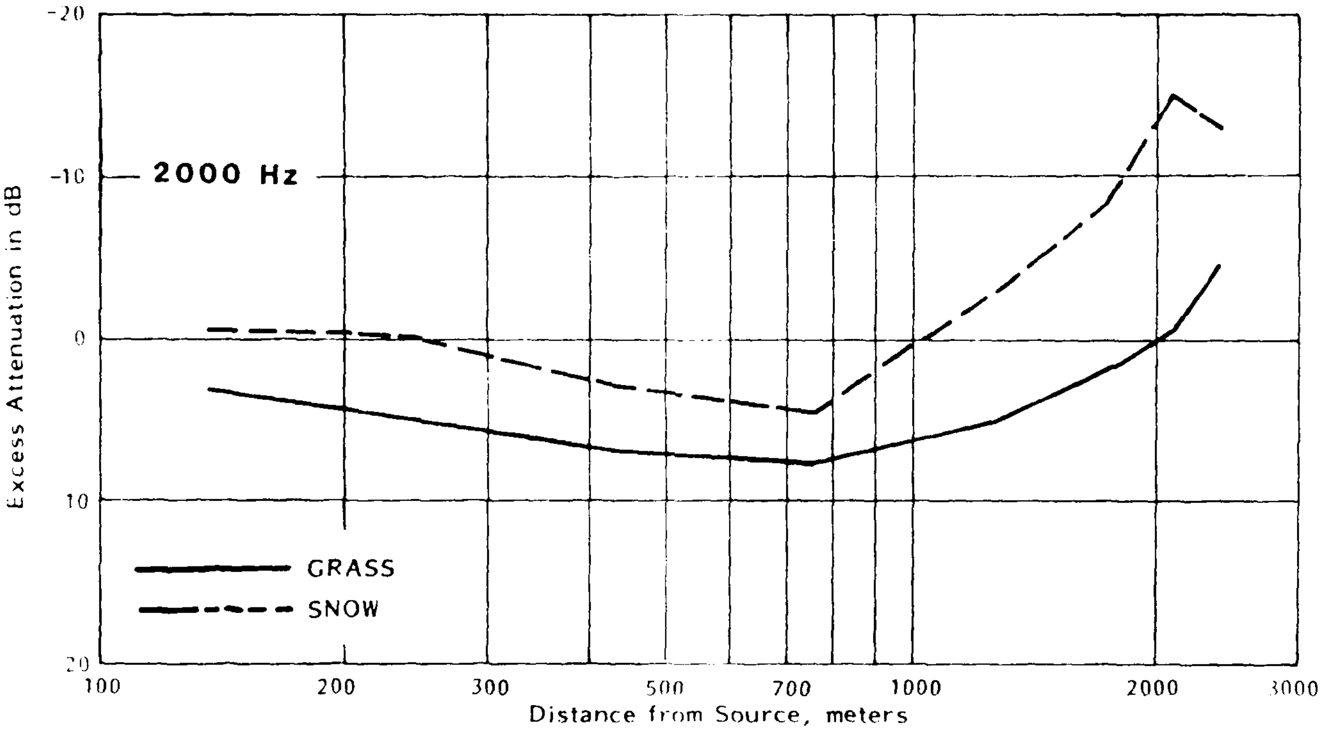

FIGURE 16 F. AVERAGE EXCESS ATTENUATION VARIATION WITH DISTANCE FOR GRASS OR SNOW COVER UNDER LOW WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT CONDITIONS

and grass [illegible] at lower frequencies [illegible] excess of 20[illegible] meters [illegible] results in smaller [illegible] generally at frequencies [illegible].

Theoretical [illegible] conditions, approximated by the [illegible] Figures 15 and [illegible] with the [illegible] cussed in Section [illegible].

4.2 ESA Variations with Temperature Gradient and Wind Component

The regression analysis had established that [illegible] wind component were the most important meteorological [illegible]. This section examines the variation in measured ESA values [illegible] wind component [illegible], for the grass ground cover condition [illegible] excluding the data with [illegible].

Figures [illegible] of wind component values [illegible] neutral temperature gradient conditions [illegible] 17-G show the average [illegible] the five different wind component ranges [illegible] frequency. Average [illegible] A-level values [illegible] average excess [illegible] the five wind [illegible] ranges as a [illegible] bands at [illegible] and A-weighted [illegible].

[illegible] age ESA values [illegible] with [illegible] through [illegible].

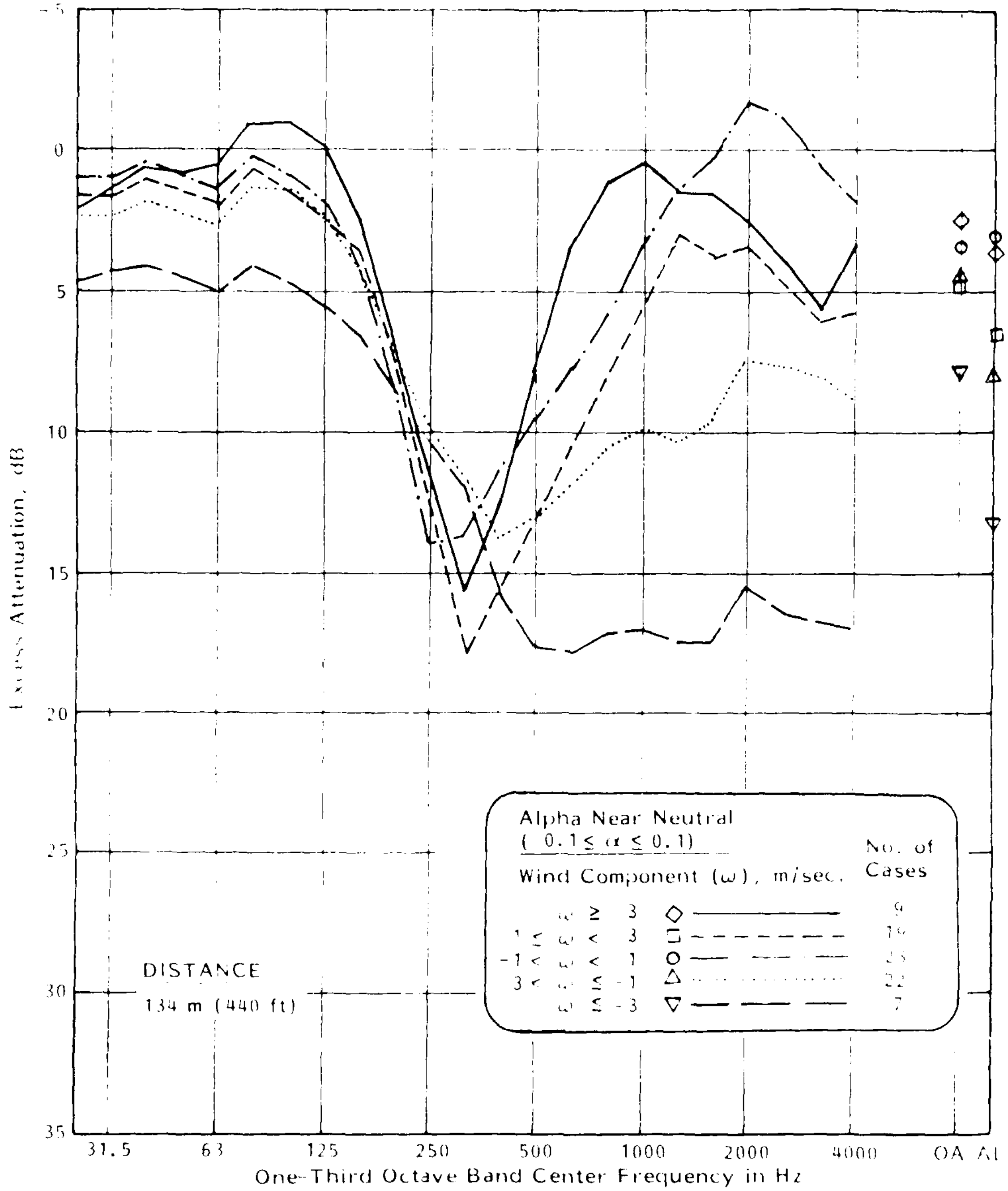

FIGURE 17 A. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS DISTANCE 134 m (440 ft)

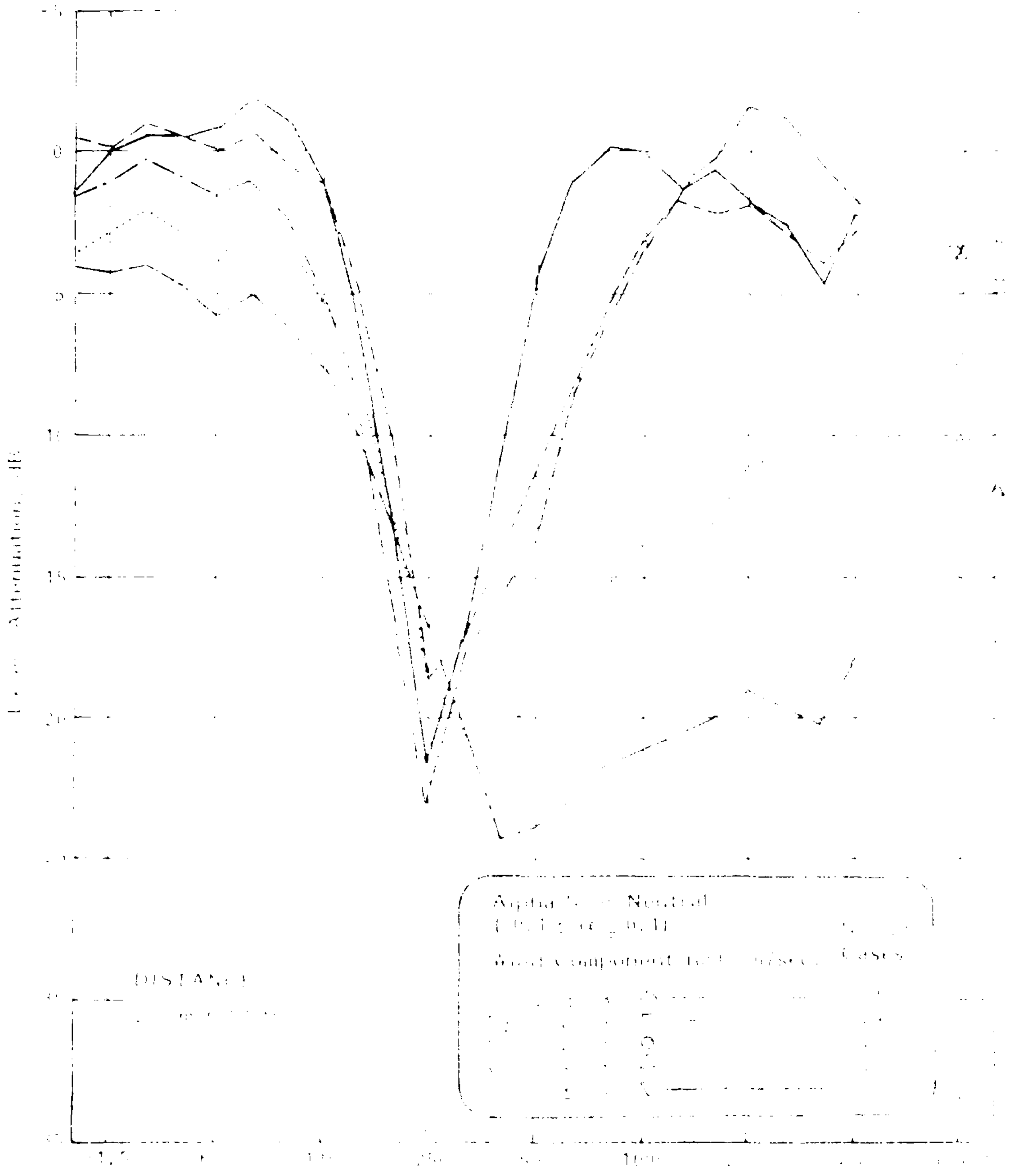

FIGURE 7(c) VARIATION IN EXCESS ATTENUATION WITH [illegible] UNDER NEAR NEUTRAL TEMPERATURE GRADIENT [illegible]

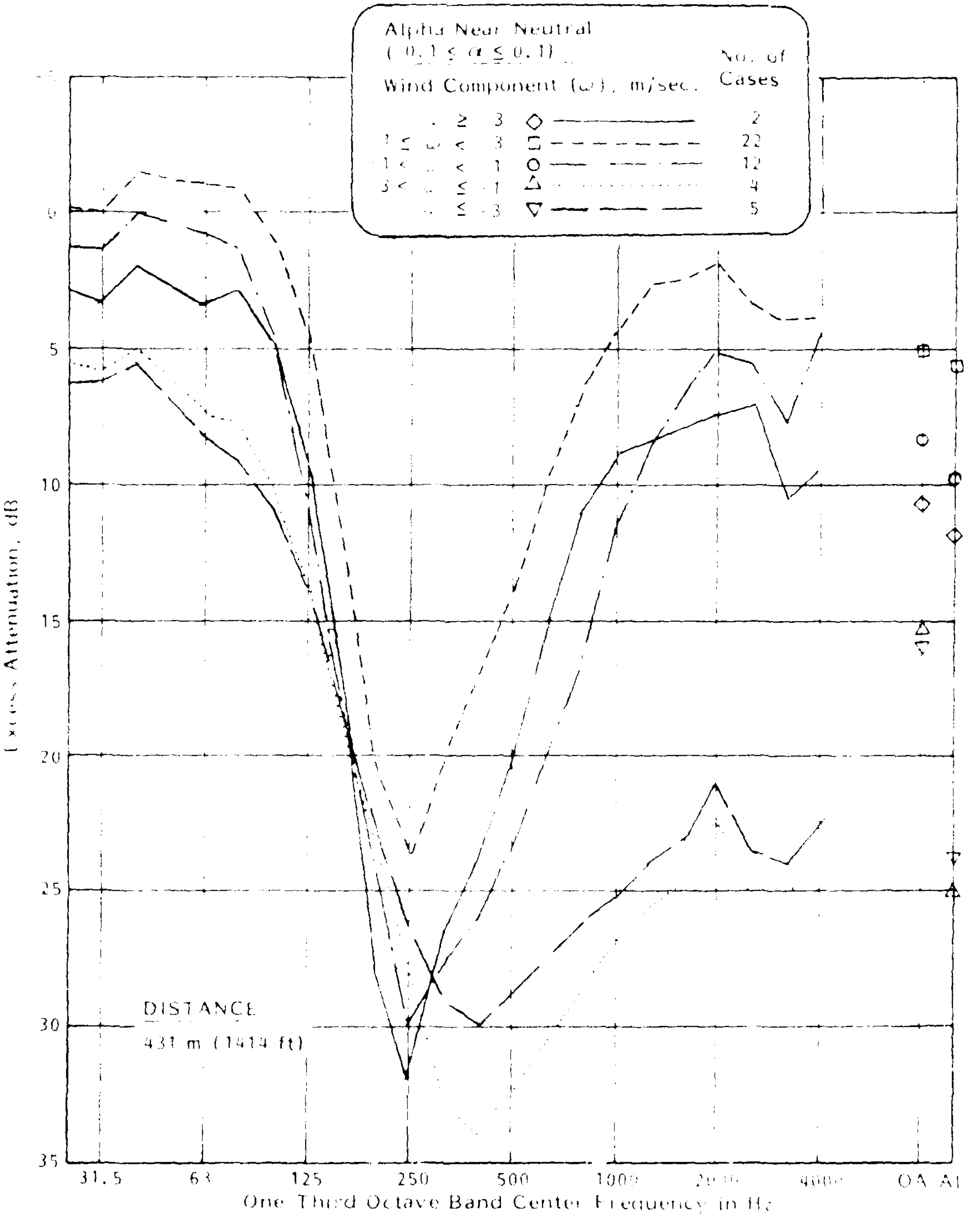

FIGURE 12.6 VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS DISTANCE 431 m (1414 ft)

AD-A142 420 OVERGROUND EXCESS SOUND ATTENUATION (ESA) VOLUME 2 2/2
ANALYSIS OF DATA FOR F..(U) BOLT BERANEK AND NEWMAN INC
CANOGA PARK CA D E BISHOP FEB 84 BBN-5324
UNCLASSIFIED AFAMRL-TR-84-017-VOL-2 F33615-82-C-0501 F/G 20/1 NL

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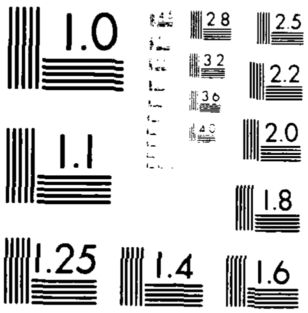
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

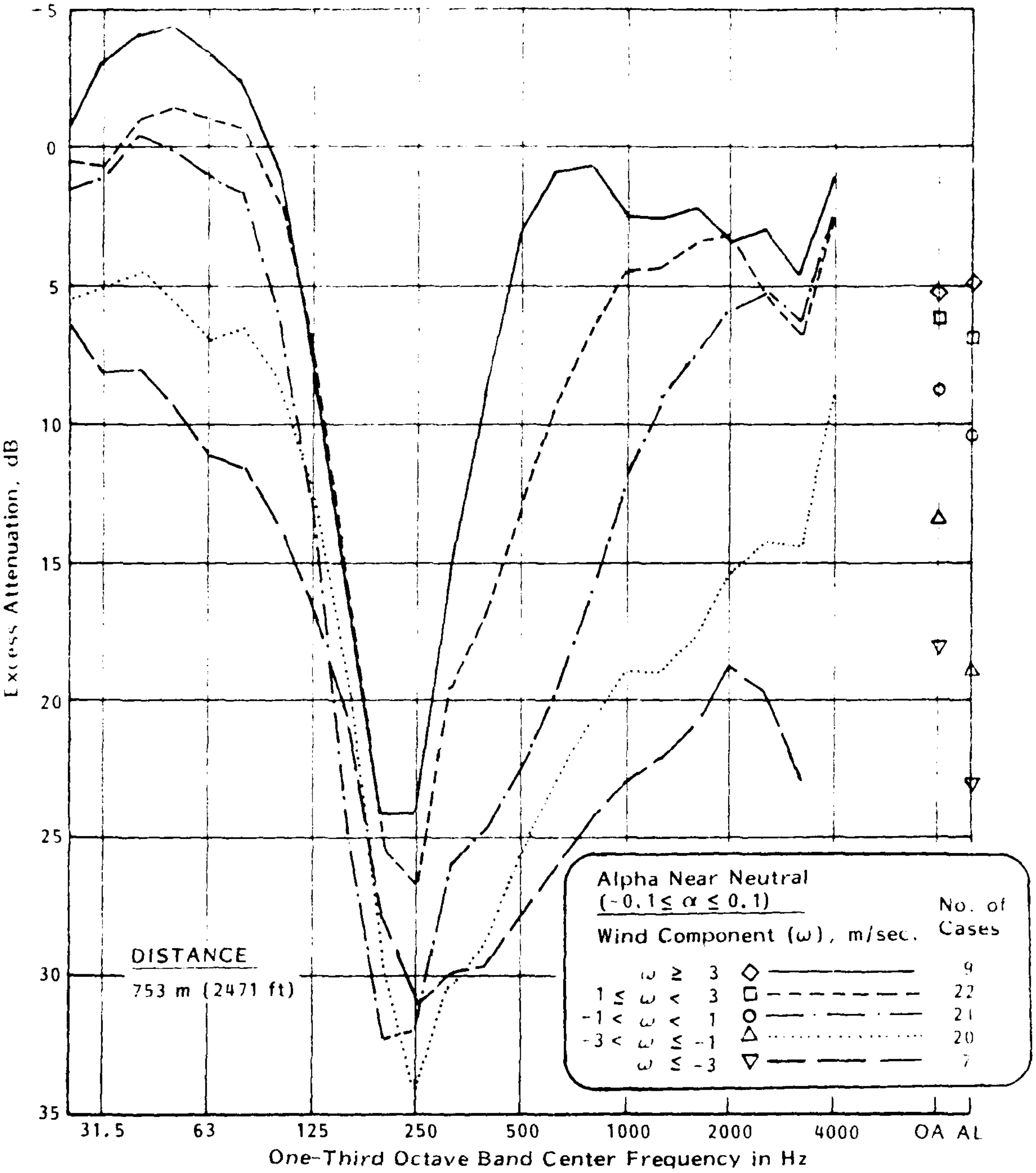

FIGURE 17 D. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS DISTANCE 753 m (2471 ft)

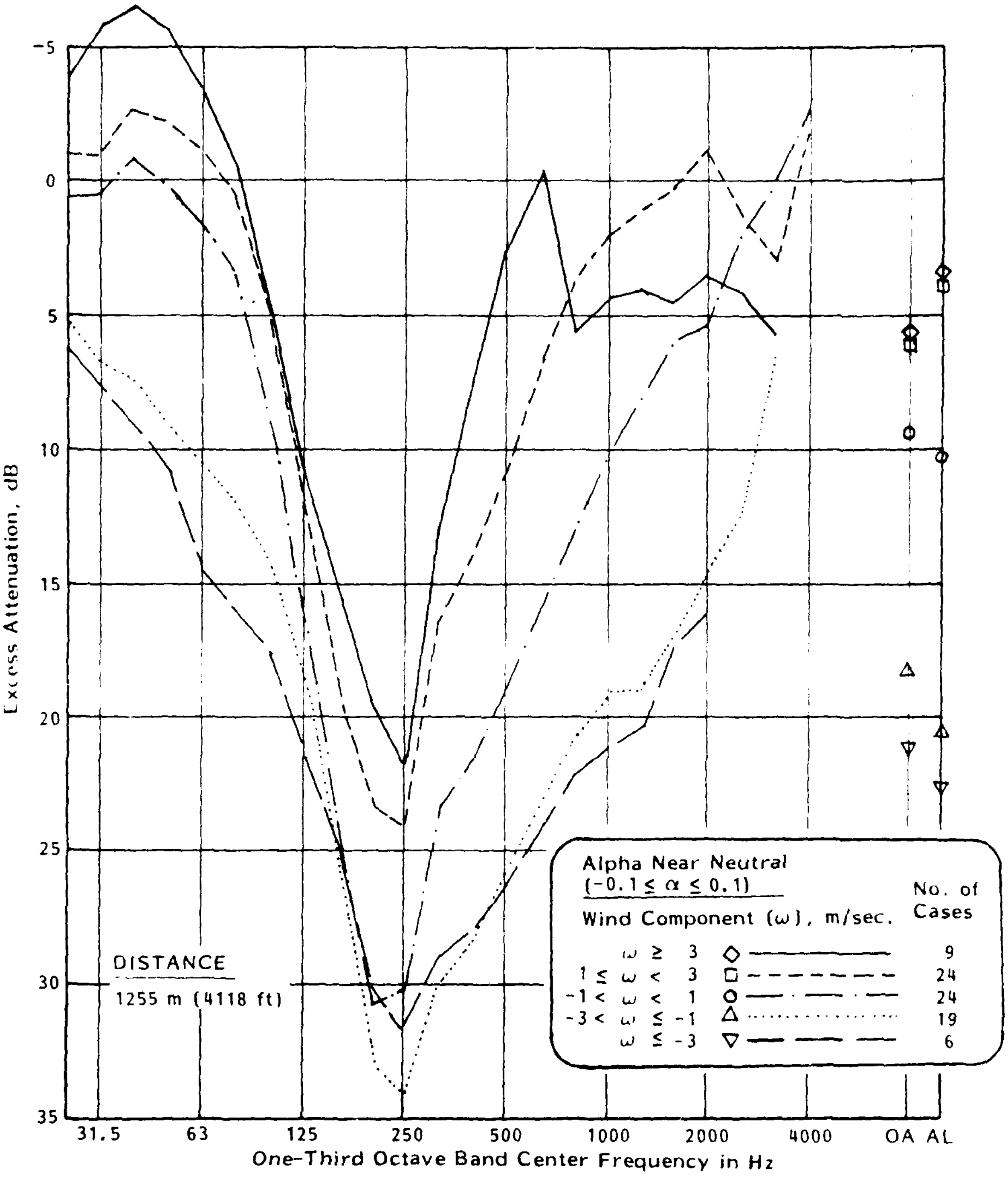

FIGURE 17-E. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS DISTANCE 1255 m (4118 ft)

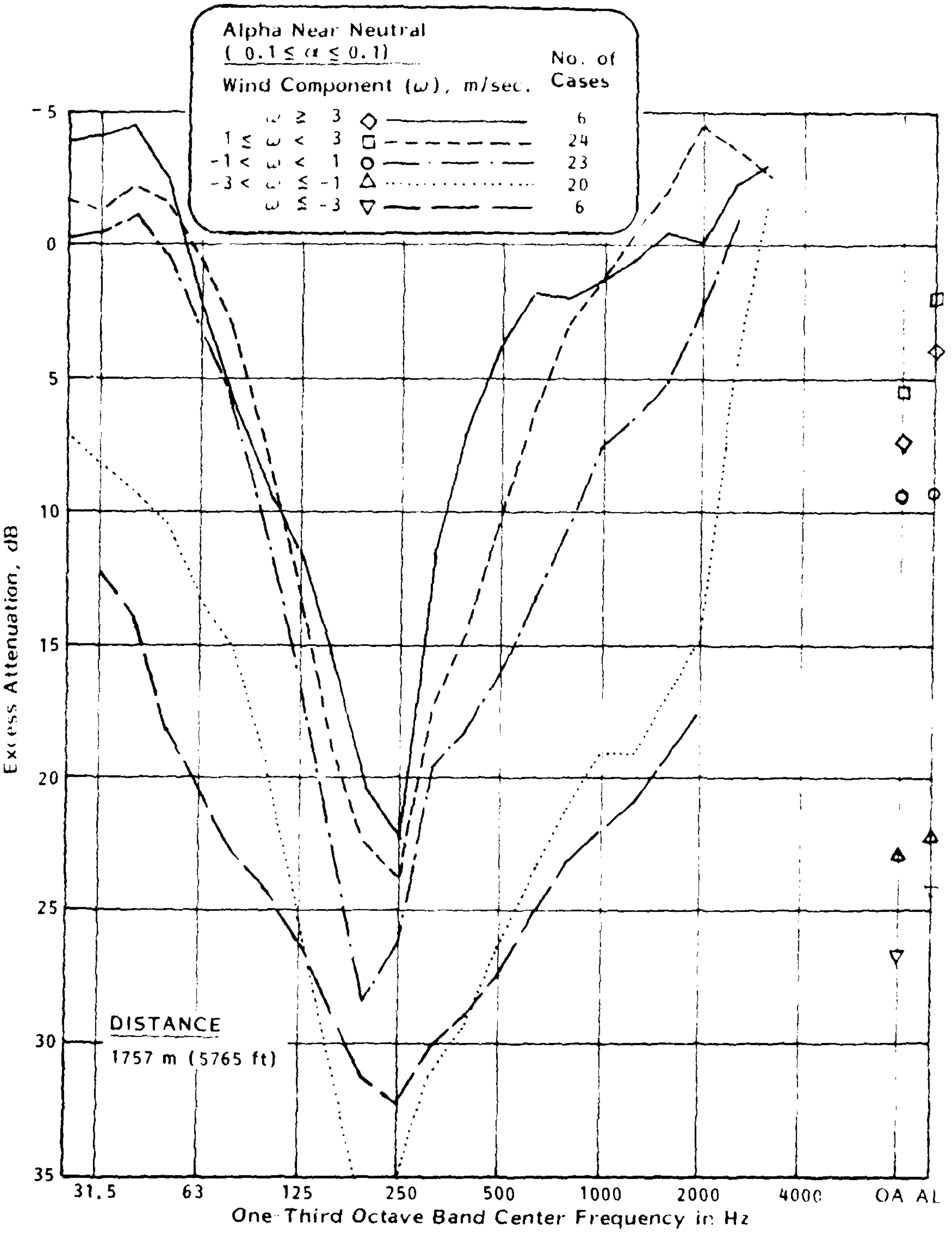

FIGURE 17-F. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS DISTANCE 1757 m (5765 ft)

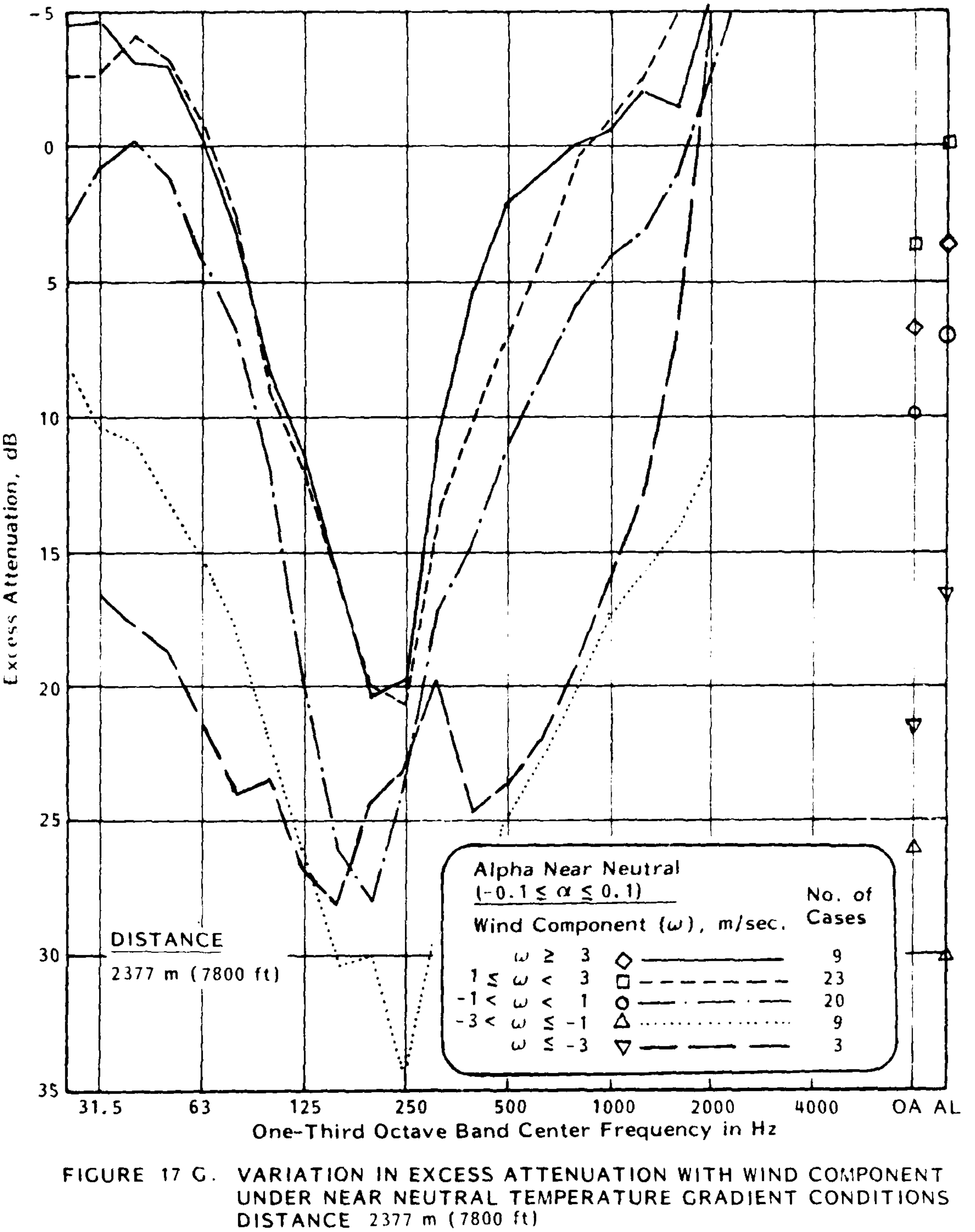

FIGURE 17 G. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS DISTANCE 2377 m (7800 ft)

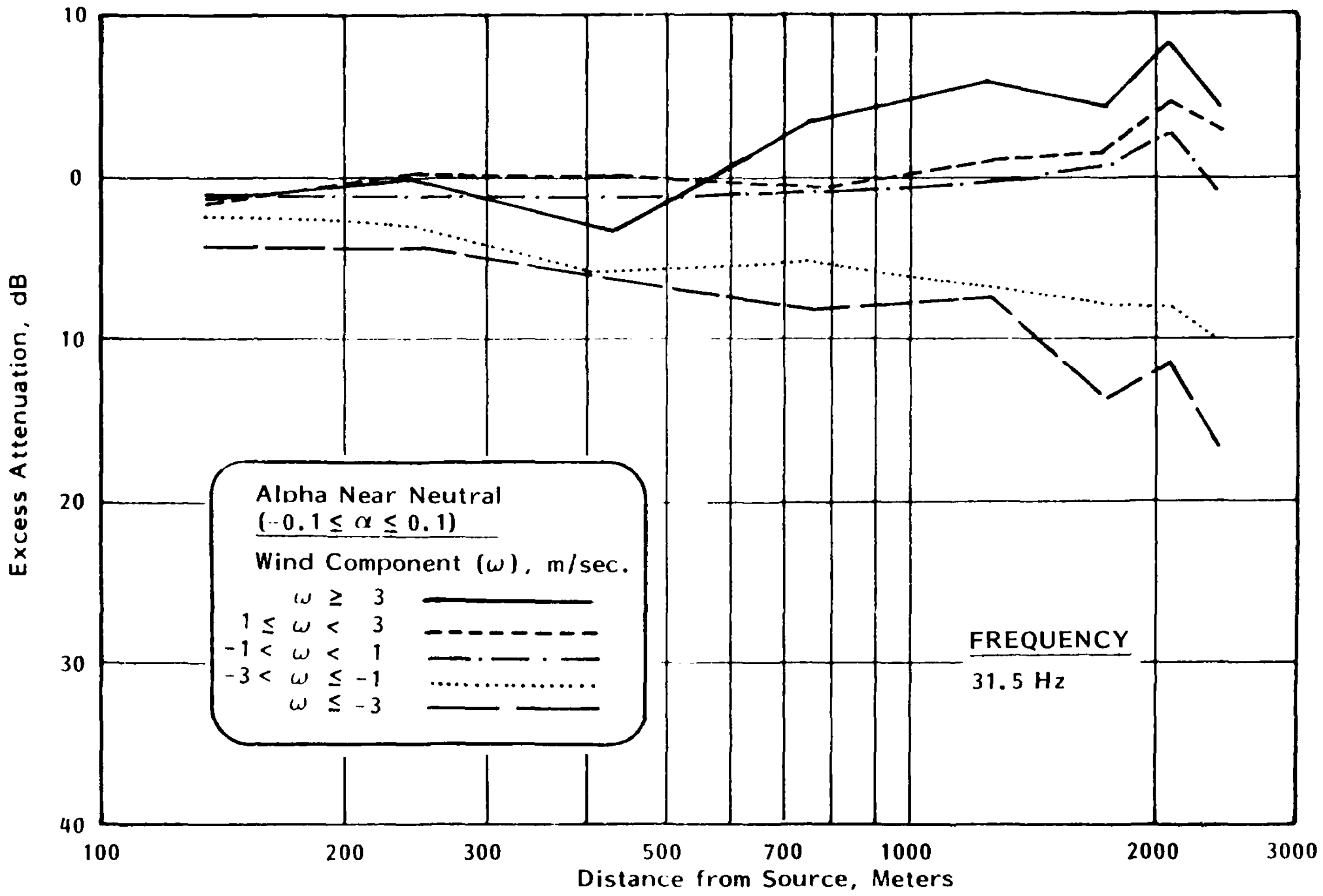

FIGURE 18 A. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS - 31.5 Hz ONE-THIRD OCTAVE FREQUENCY BAND

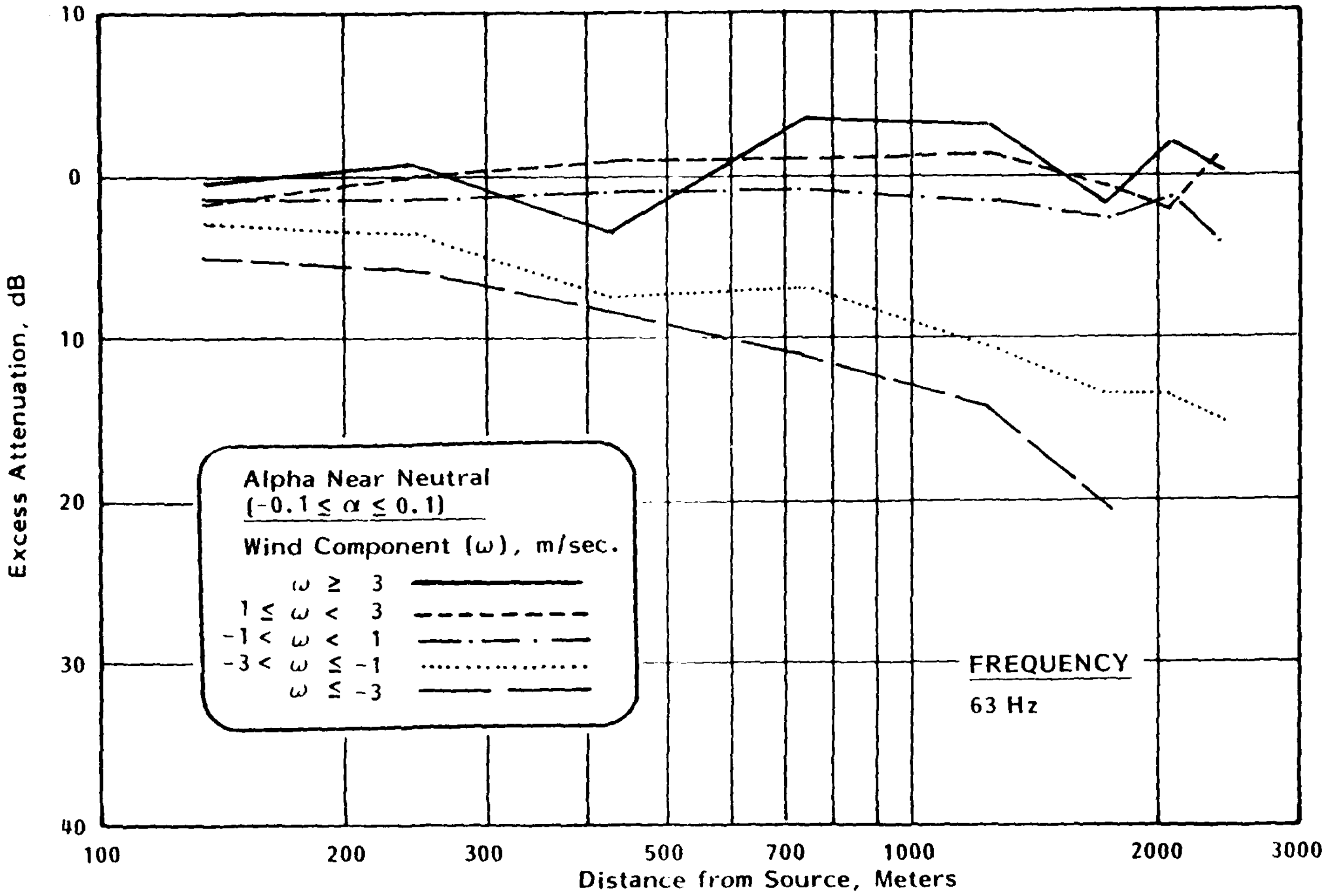

FIGURE 18-B. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS – 63 Hz ONE-THIRD OCTAVE FREQUENCY BAND

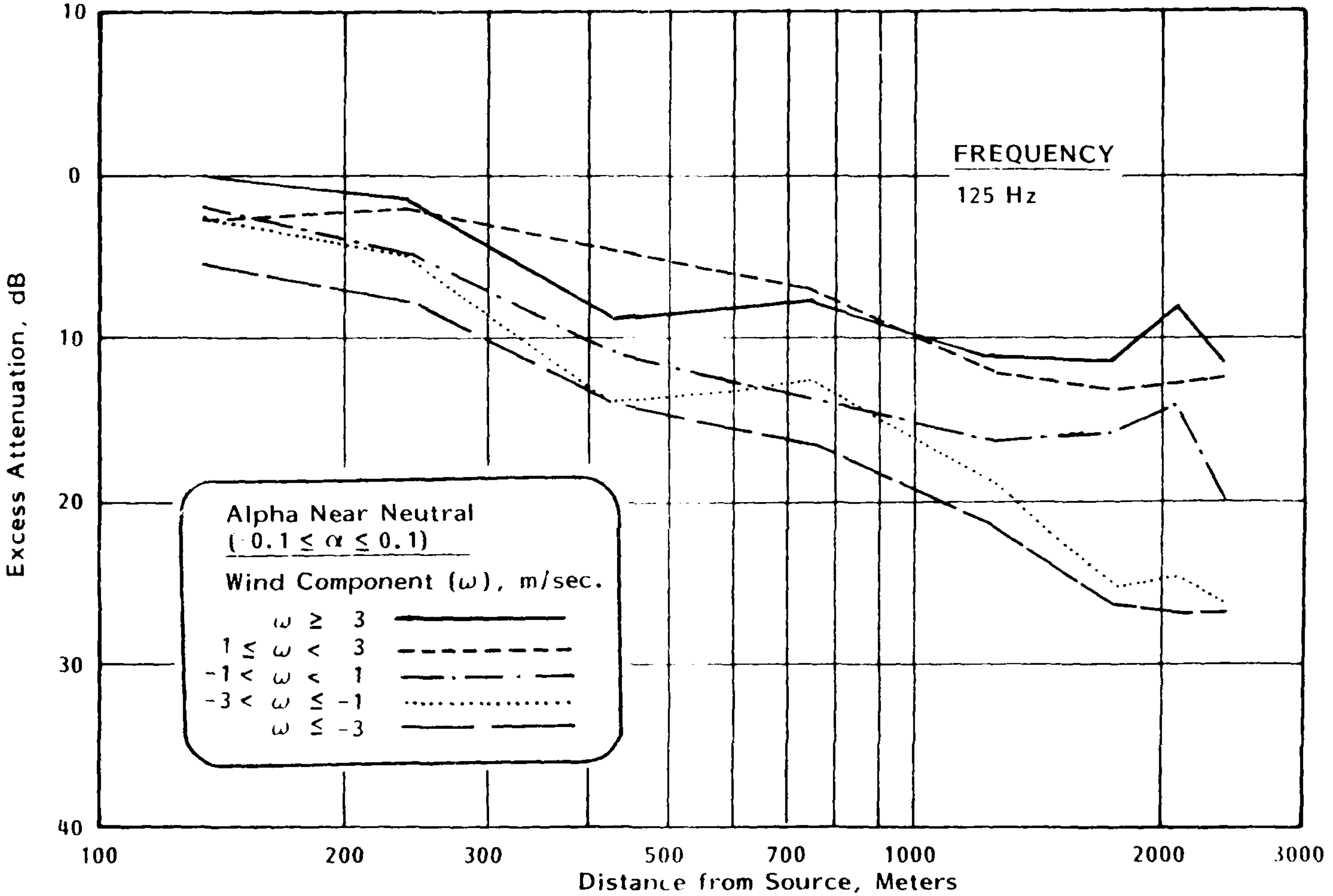

FIGURE 18 C. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS - 125 Hz ONE-THIRD OCTAVE FREQUENCY BAND

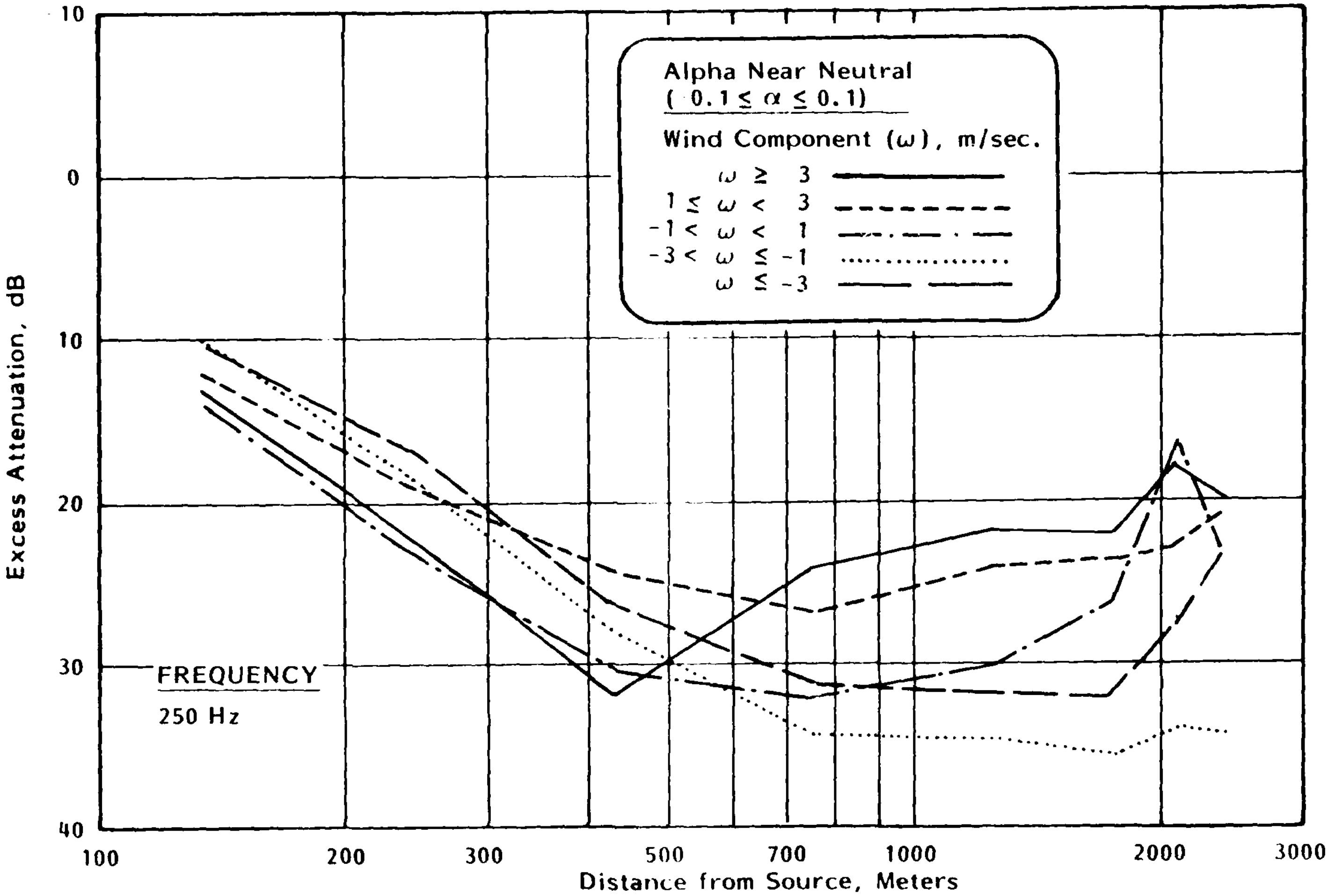

FIGURE 18-D. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS - 250 Hz ONE-THIRD OCTAVE FREQUENCY BAND

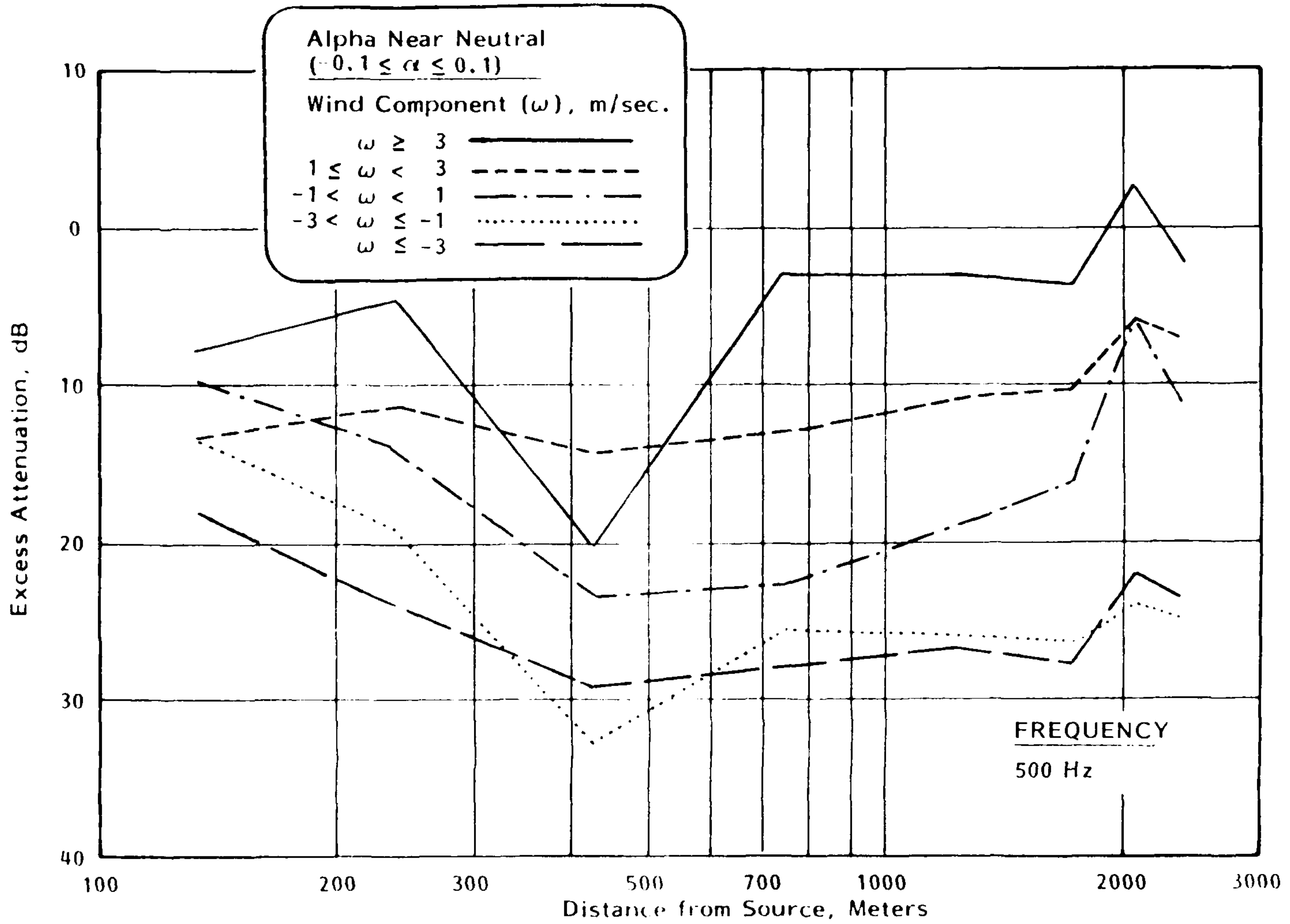

FIGURE 18 E. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS 500 Hz ONE-THIRD OCTAVE FREQUENCY BAND

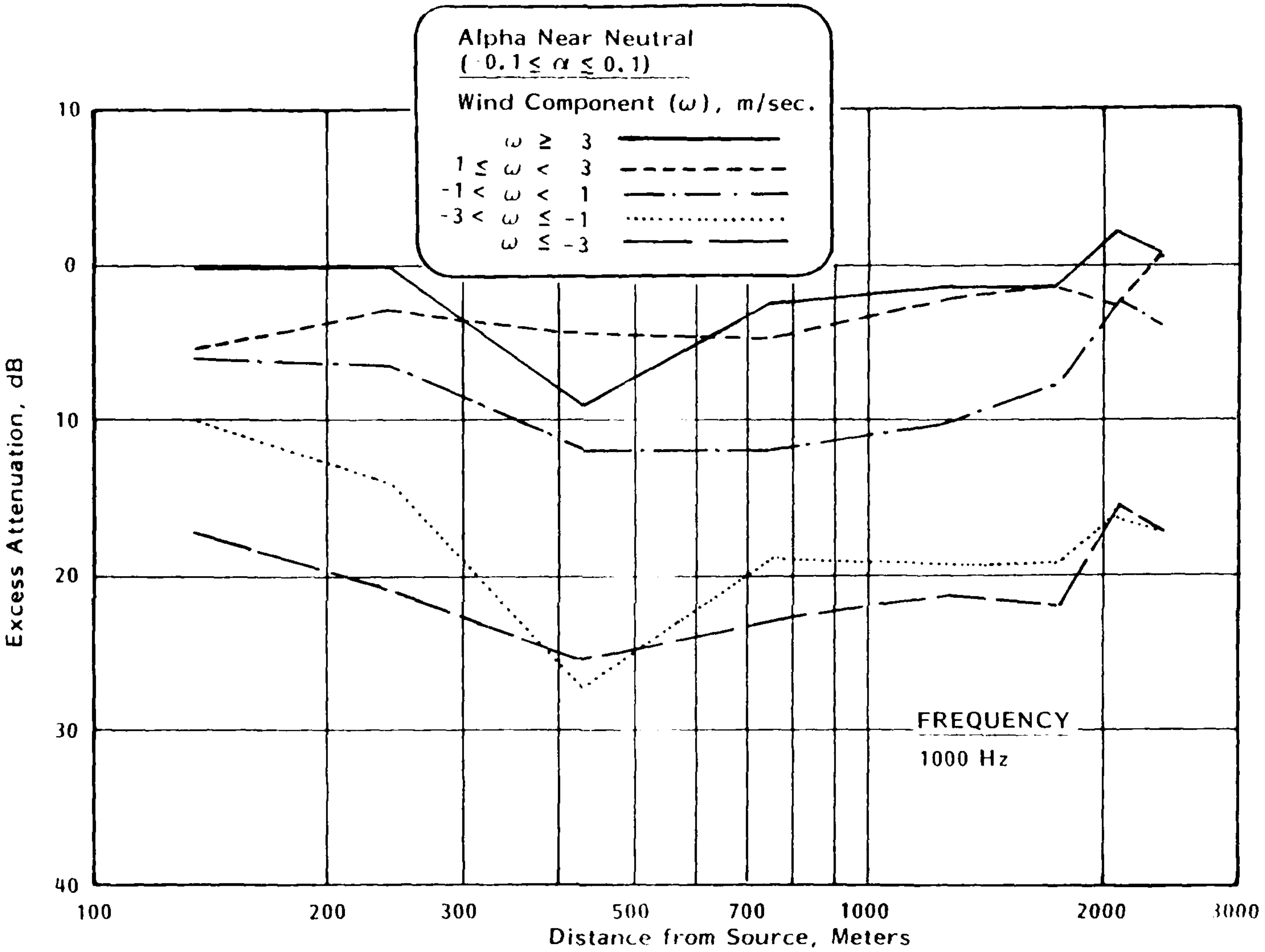

FIGURE 18 F. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS 1000 Hz ONE THIRD OCTAVE FREQUENCY BAND

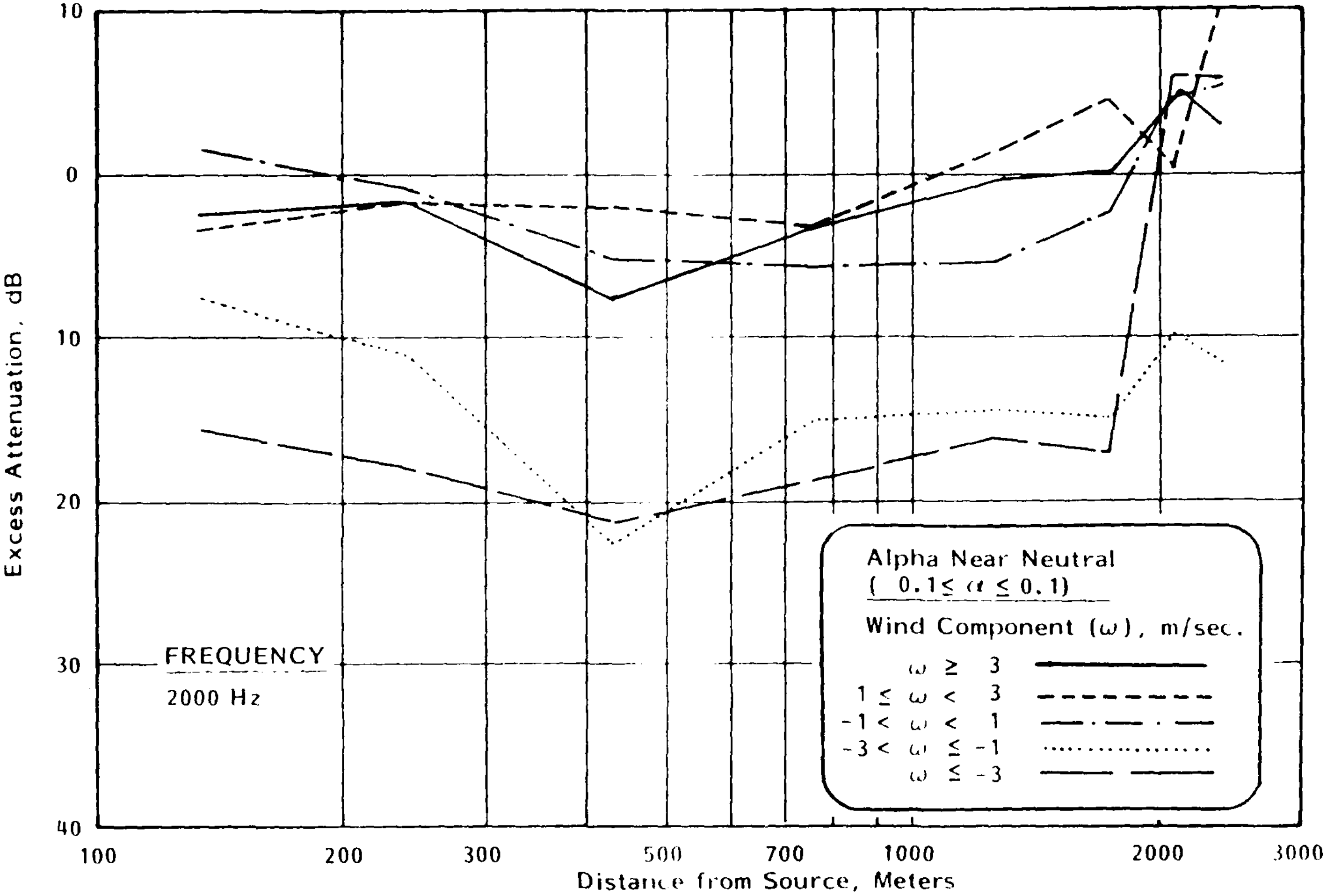

FIGURE 18 G. VARIATION IN EXCESS ATT N ITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GR IEN C DITIONS 2000 Hz ONE THIRD OCTAVE FREQUENCY BAND

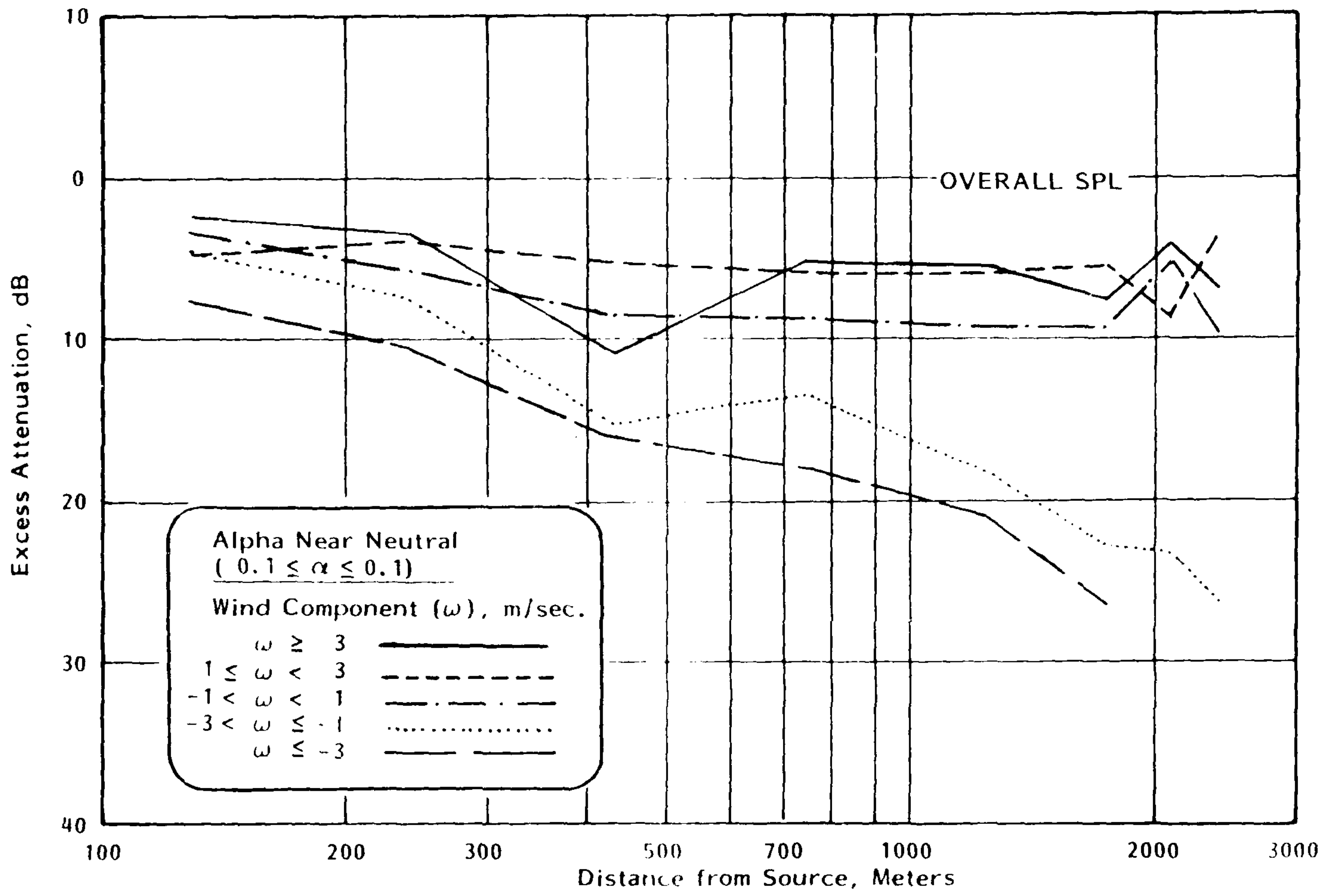

FIGURE 18 H. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS OVERALL SOUND PRESSURE LEVEL

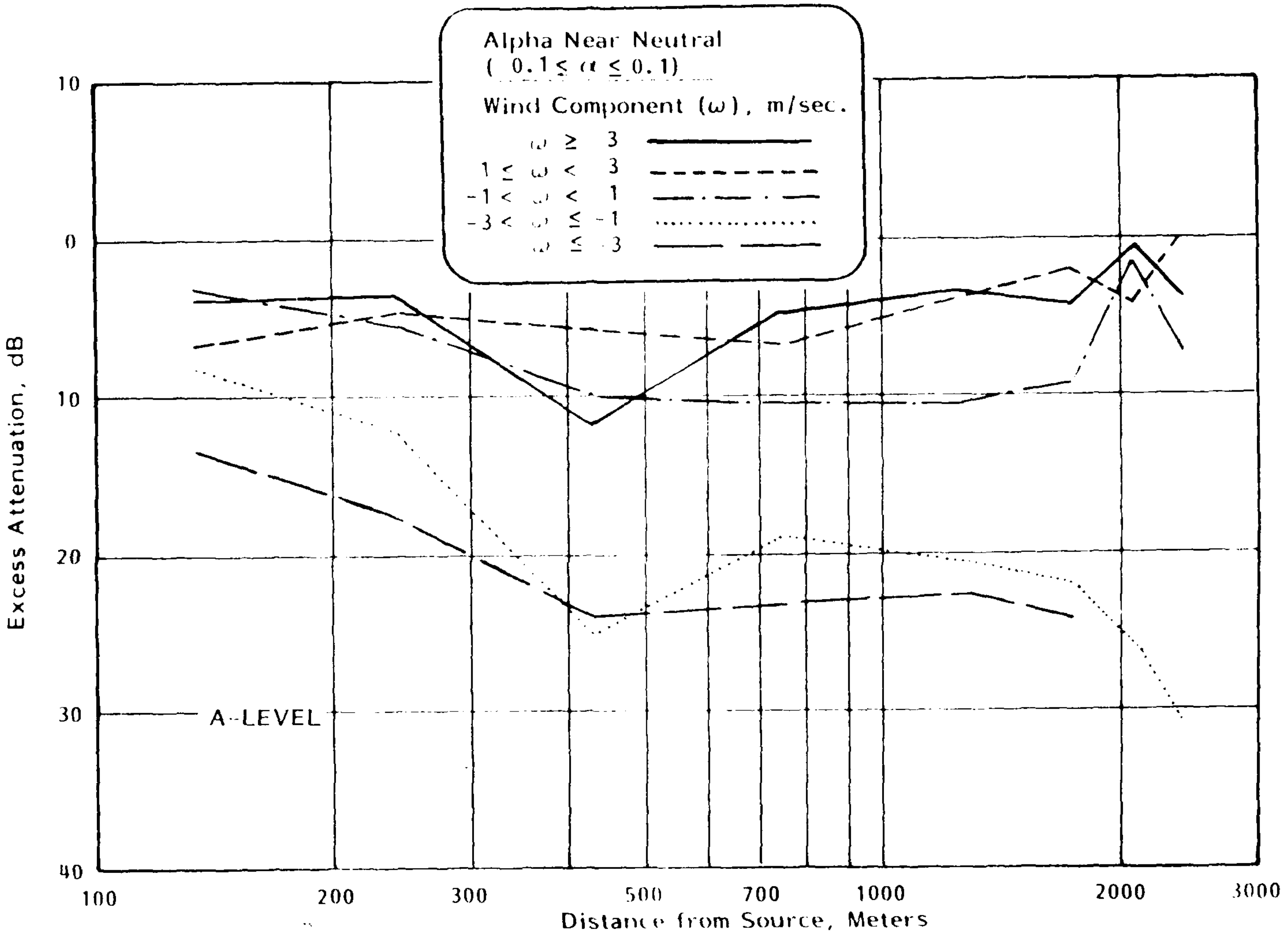

FIGURE 18.1. VARIATION IN EXCESS ATTENUATION WITH WIND COMPONENT UNDER NEAR NEUTRAL TEMPERATURE GRADIENT CONDITIONS A LEVEL

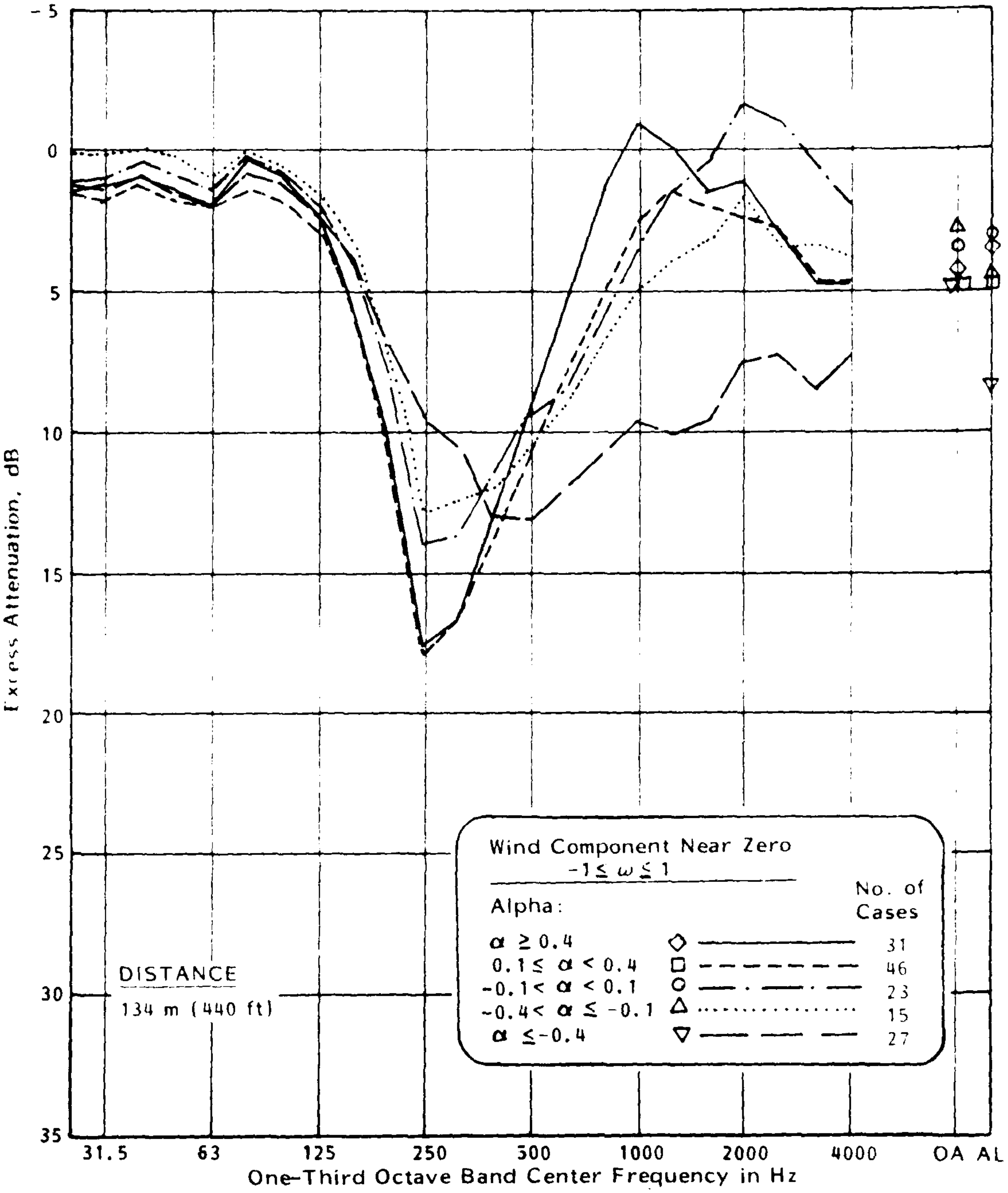

FIGURE 19 A. **VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR SMALL WIND COMPONENT CONDITIONS - DISTANCE** 134 m (440 ft)

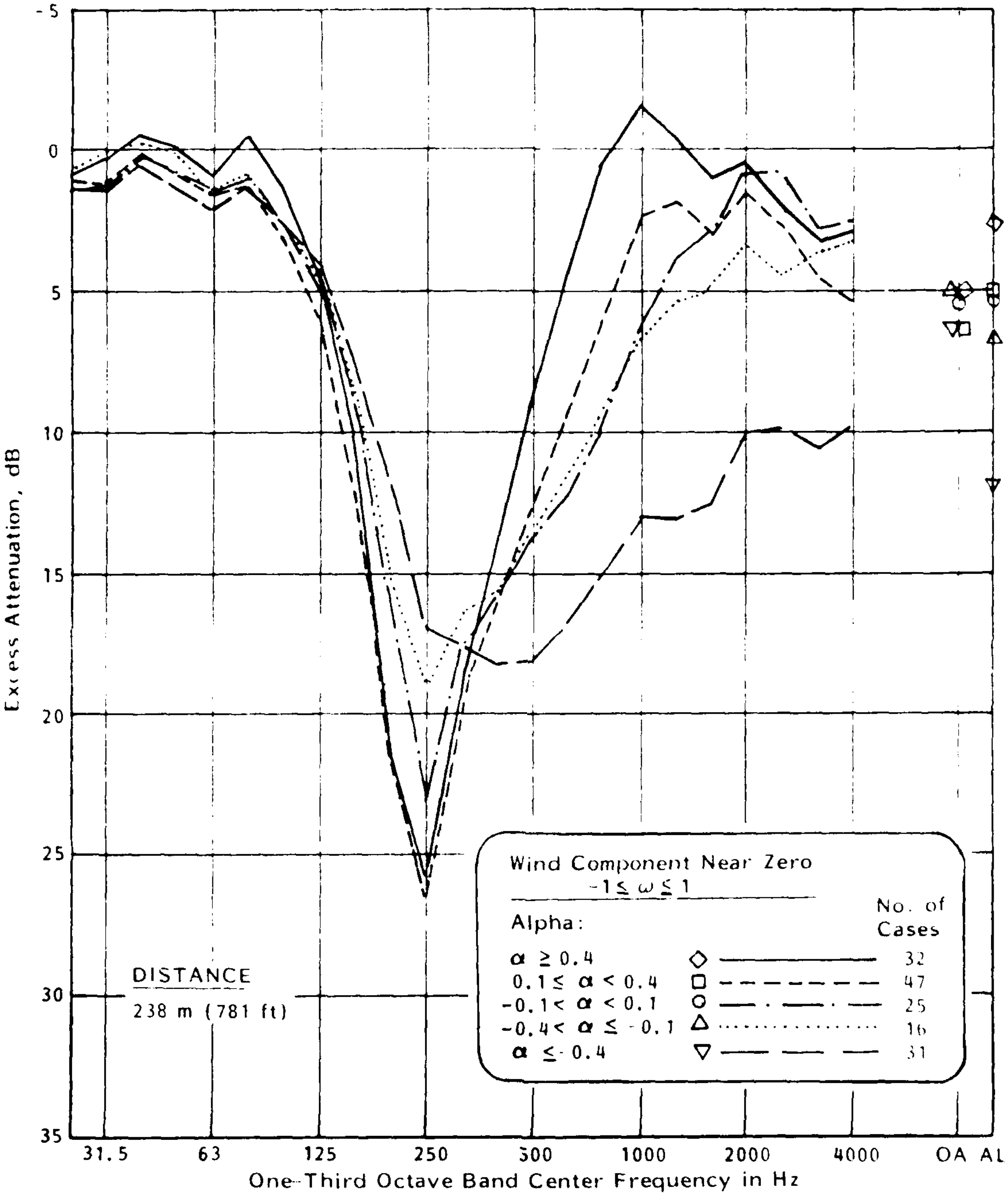

FIGURE 19-B. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR SMALL WIND COMPONENT CONDITIONS - DISTANCE 238 m (781 ft)

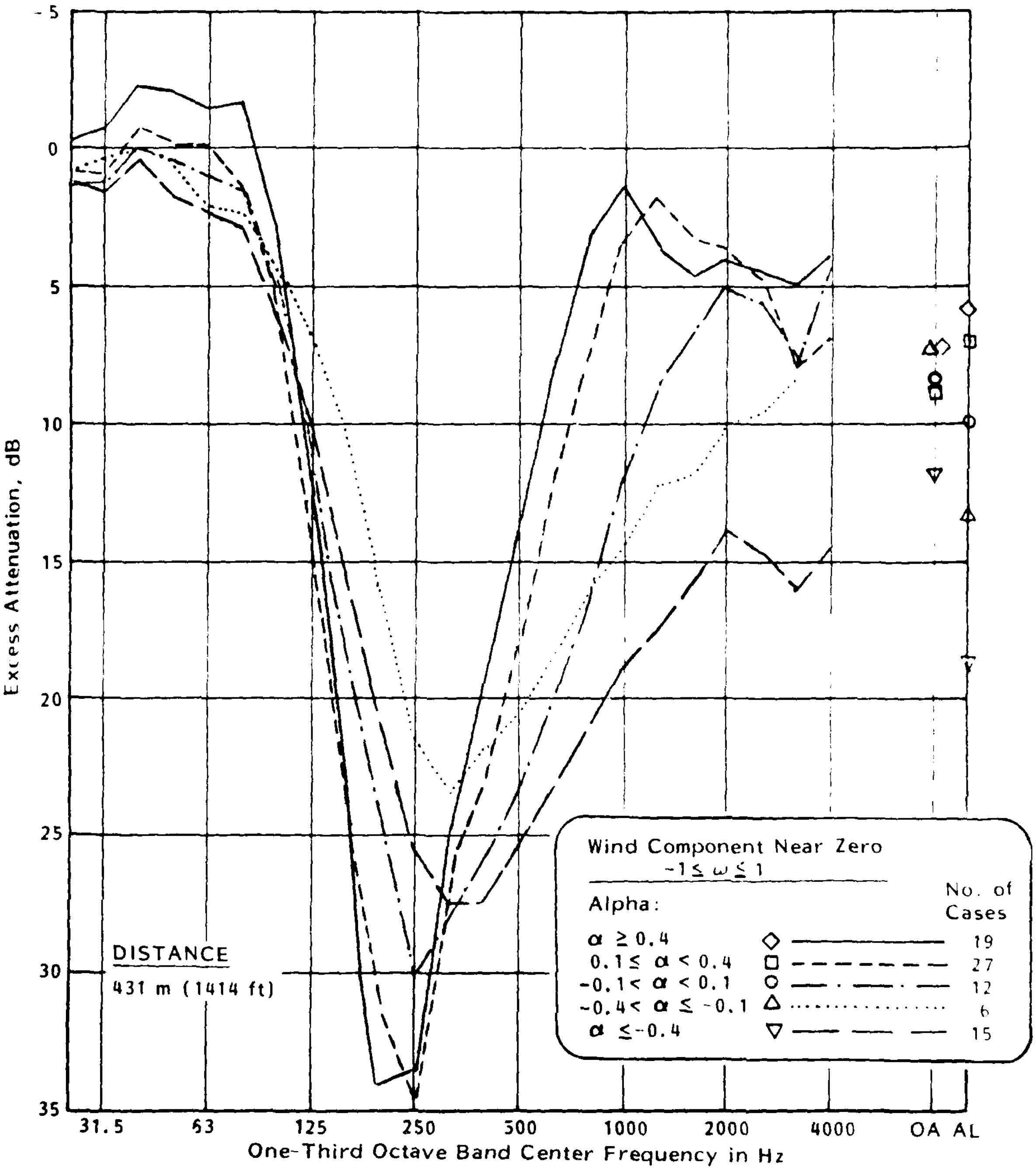

FIGURE 19 C. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR SMALL WIND COMPONENT CONDITIONS - DISTANCE 431 m (1414 ft)

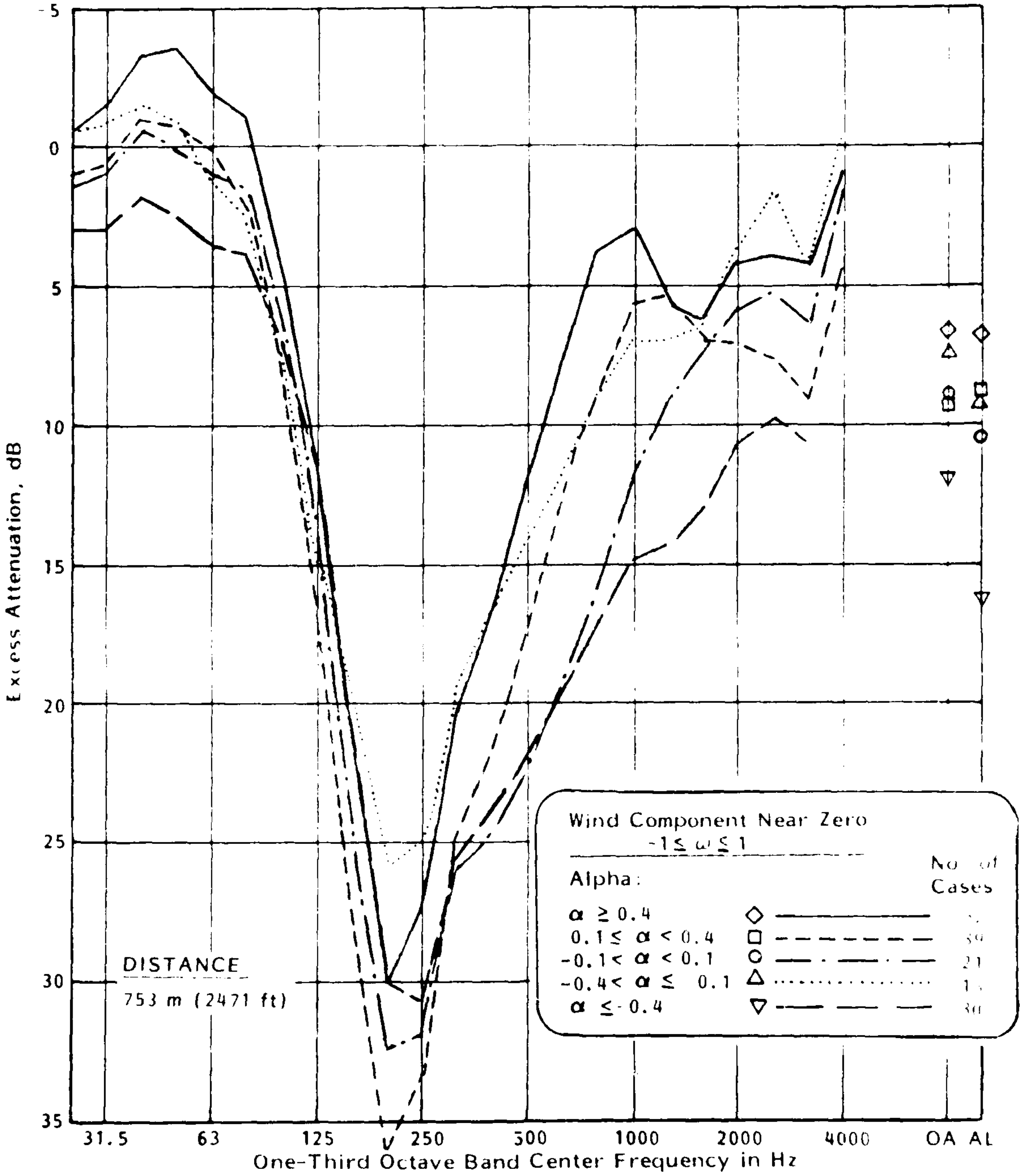

FIGURE 19 D. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR SMALL WIND COMPONENT CONDITIONS - DISTANCE 753 m (2471 ft)

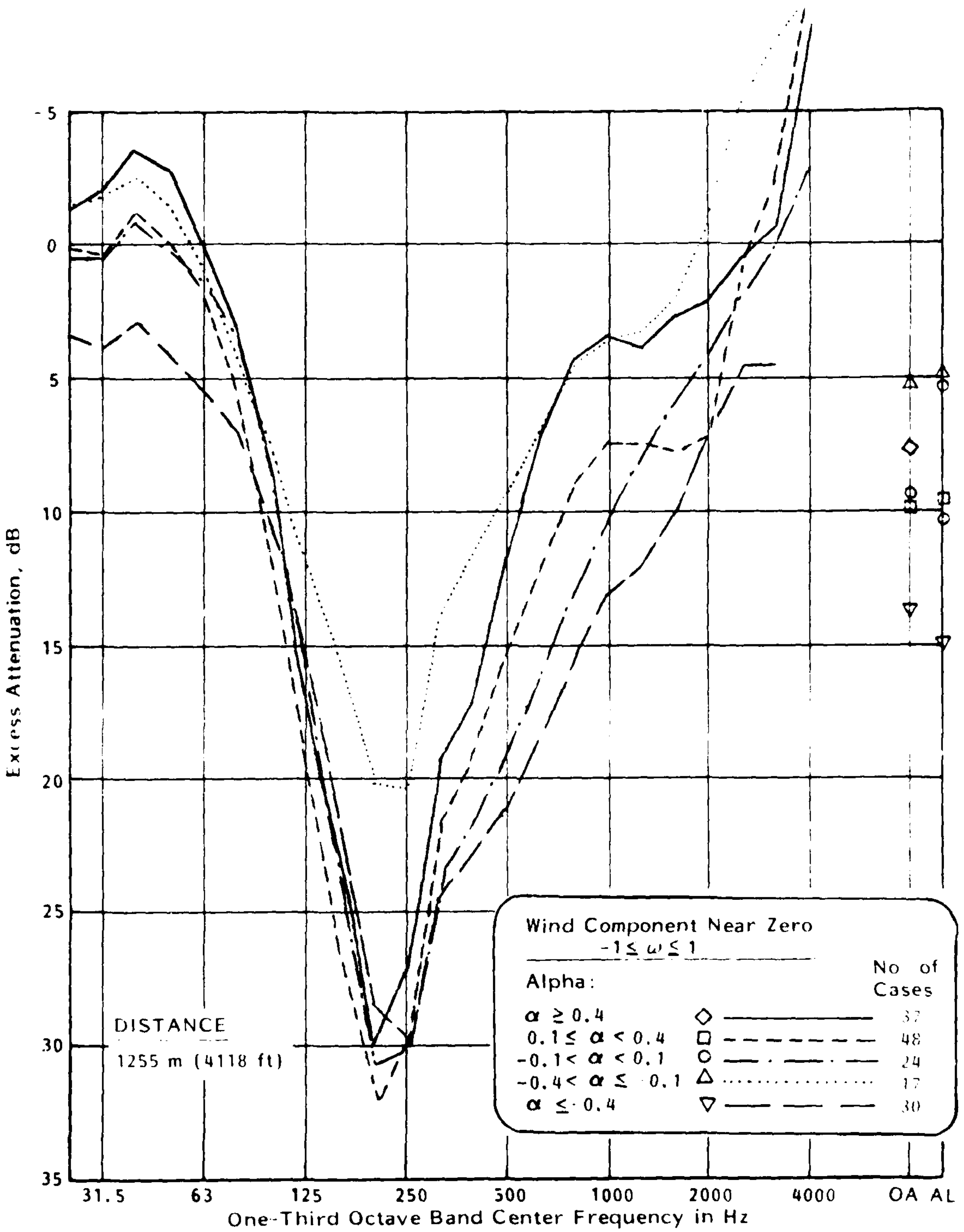

FIGURE 19 E. **VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR SMALL WIND COMPONENT CONDITIONS - DISTANCE** 1255 m (4118 ft)

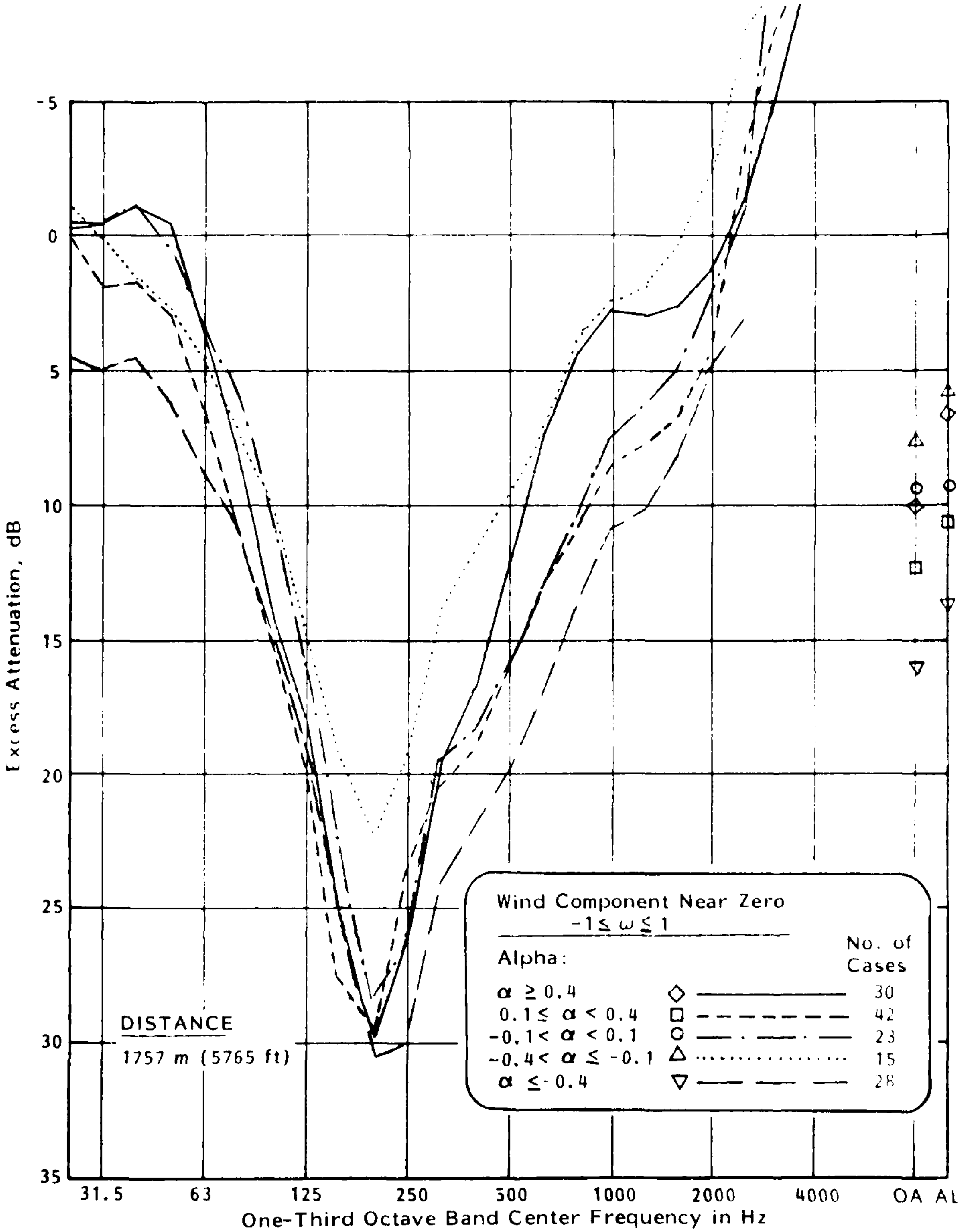

FIGURE 19 F. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR SMALL WIND COMPONENT CONDITIONS - DISTANCE 1757 m (5765 ft)

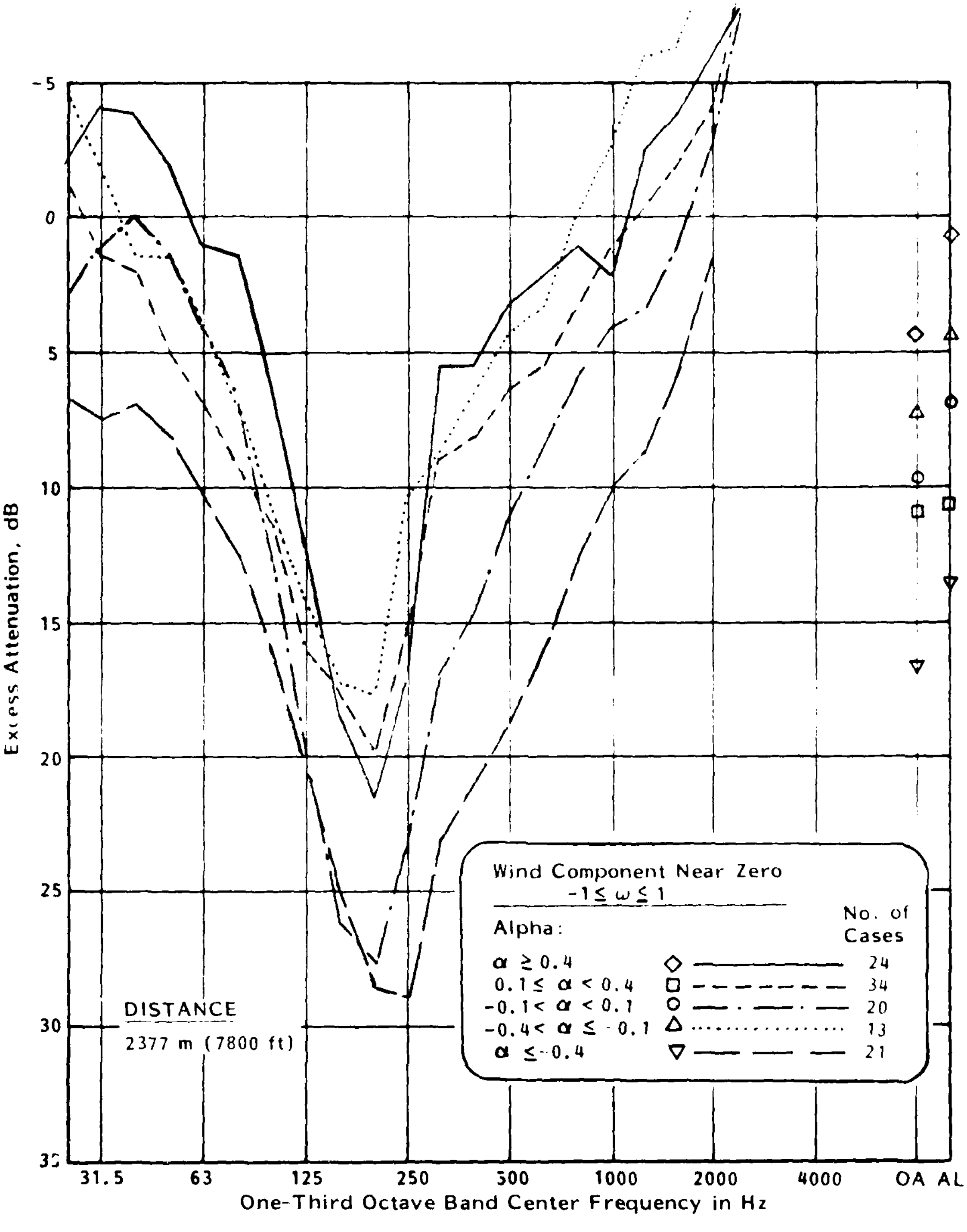

FIGURE 19 G. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR SMALL WIND COMPONENT CONDITIONS - DISTANCE 2377 m (7800 ft)

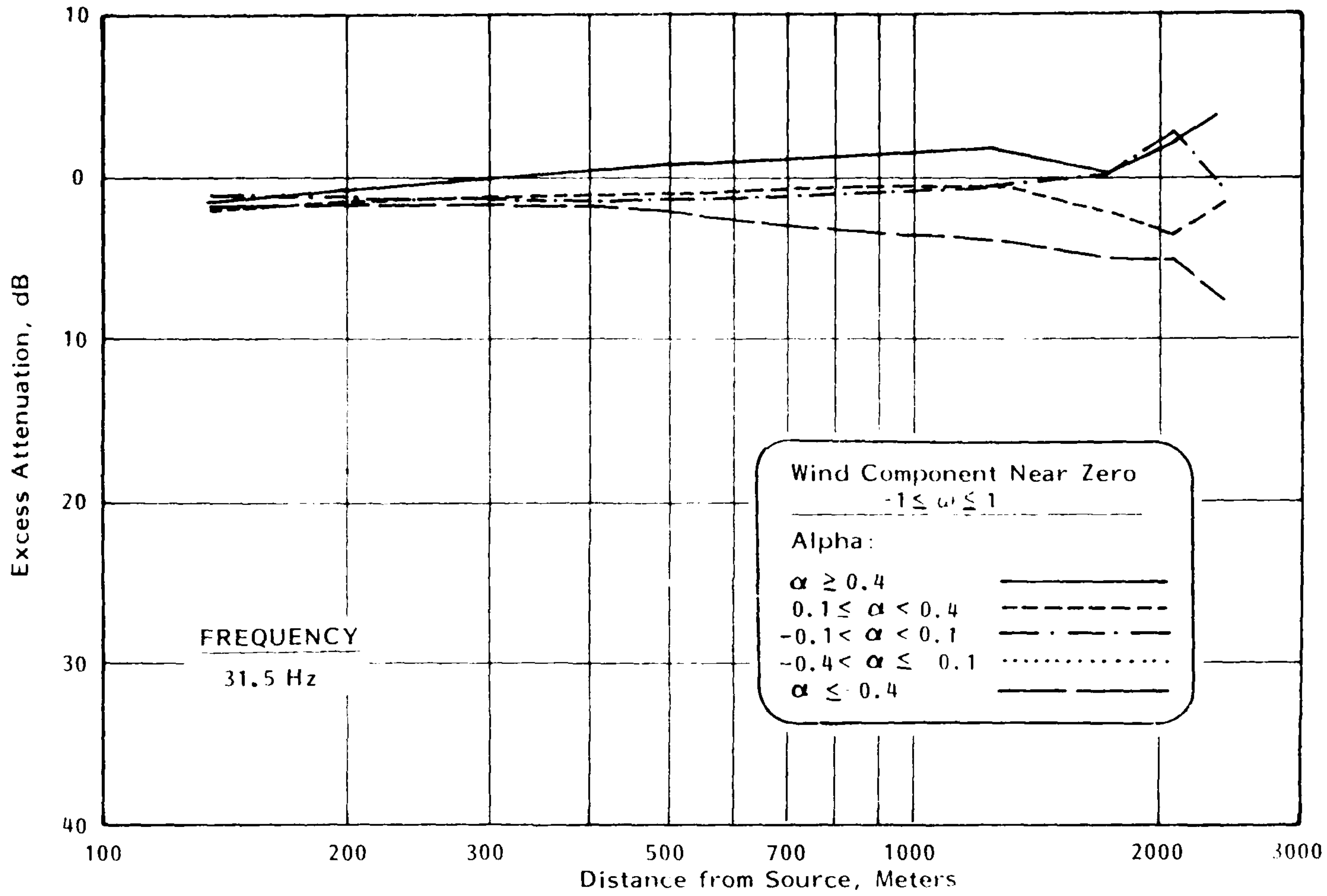

FIGURE 20 A. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS 31.5 Hz ONE THIRD OCTAVE FREQUENCY BAND

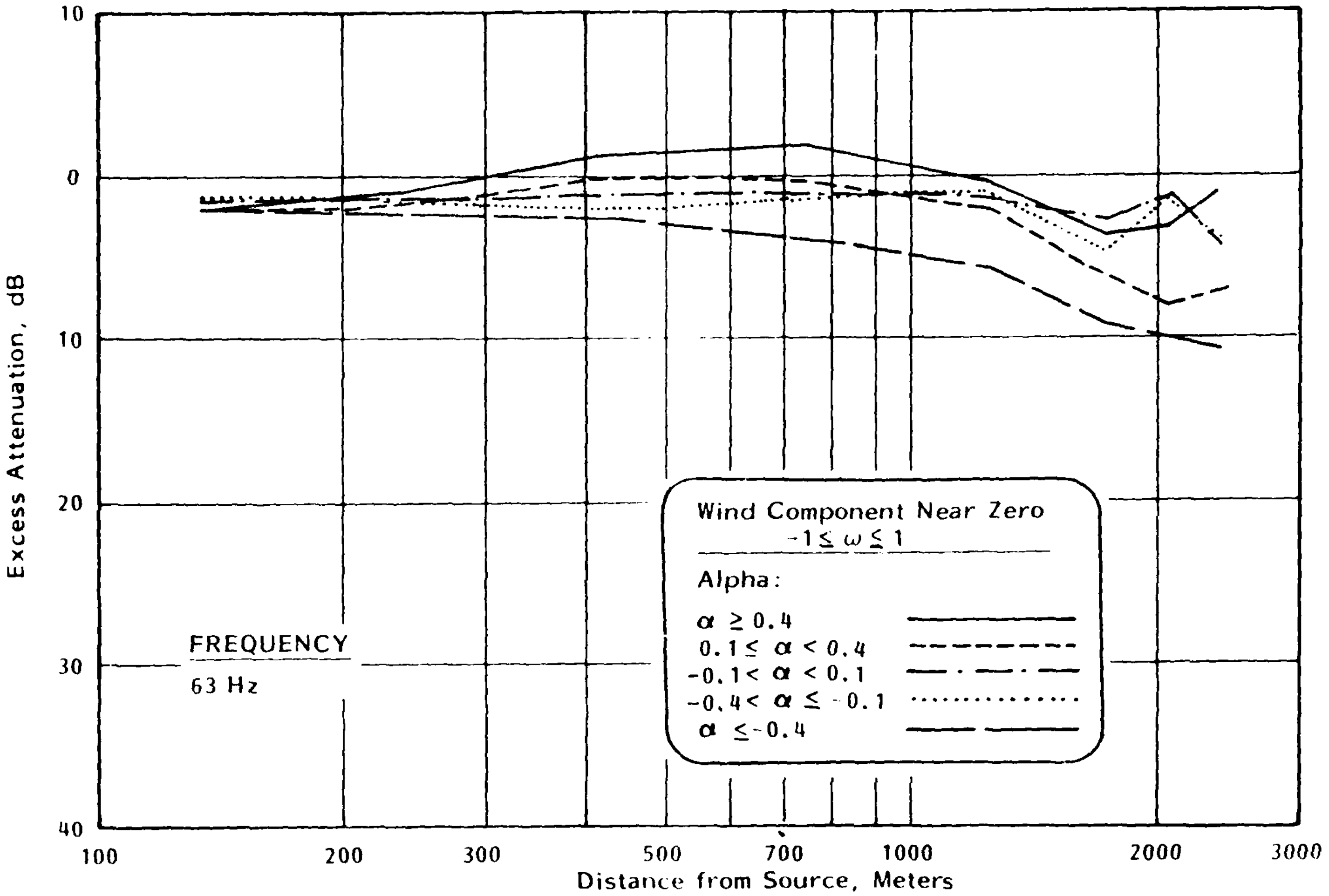

FIGURE 20 B. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS - 63 Hz ONE THIRD OCTAVE FREQUENCY BAND

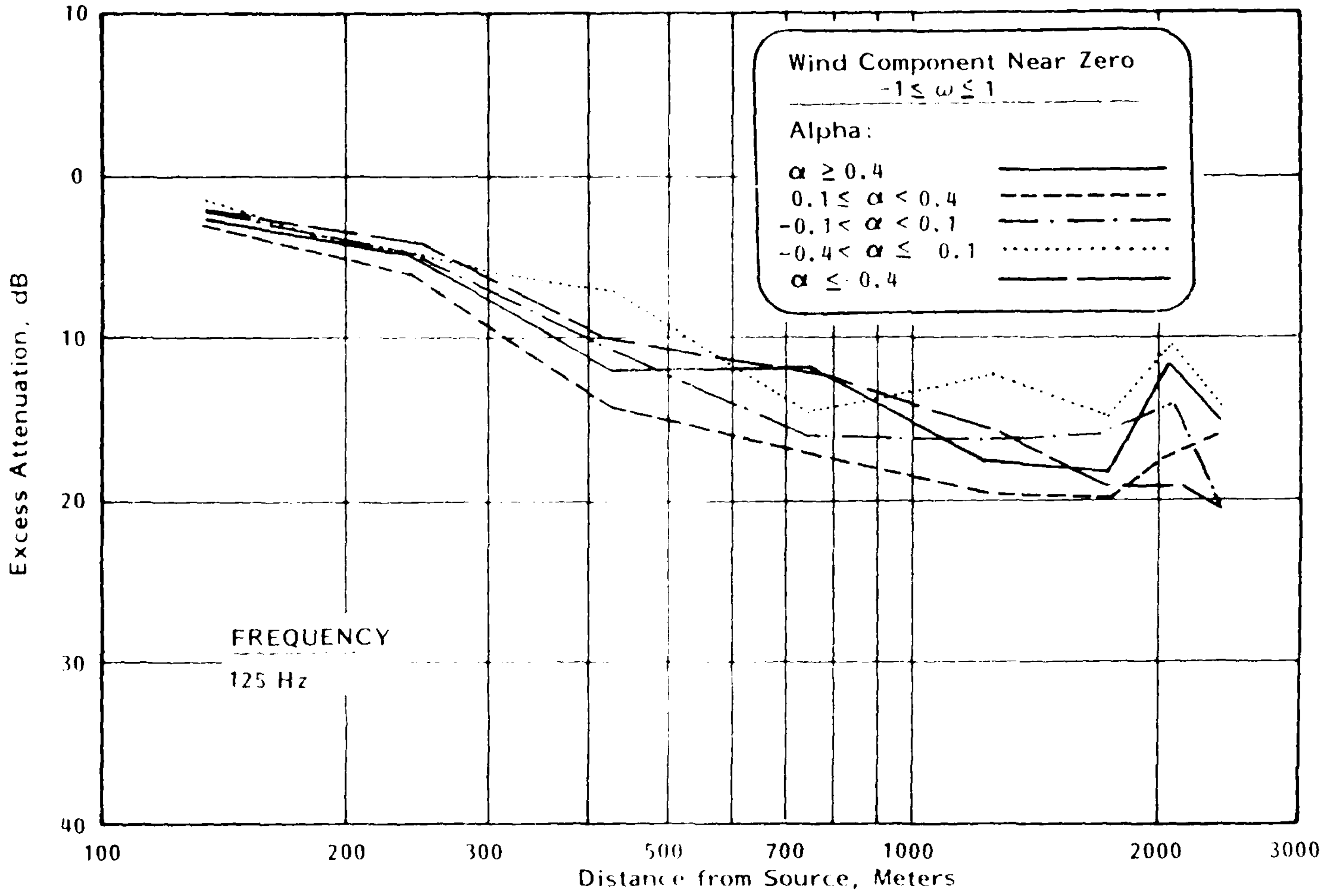

FIGURE 20 C. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS 125 Hz ONE THIRD OCTAVE FREQUENCY BAND

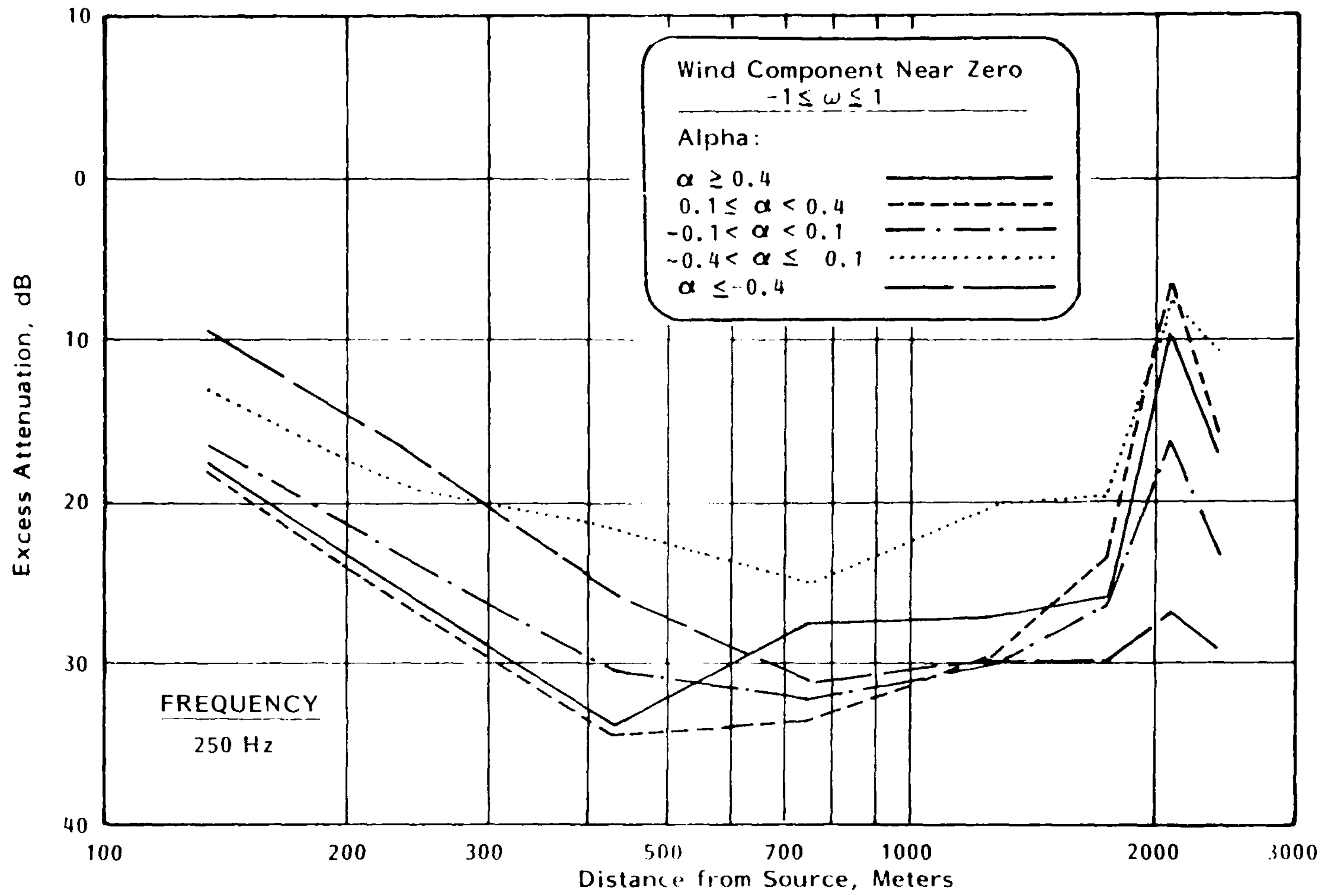

FIGURE 20 D. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS 250 Hz ONE THIRD OCTAVE FREQUENCY BAND

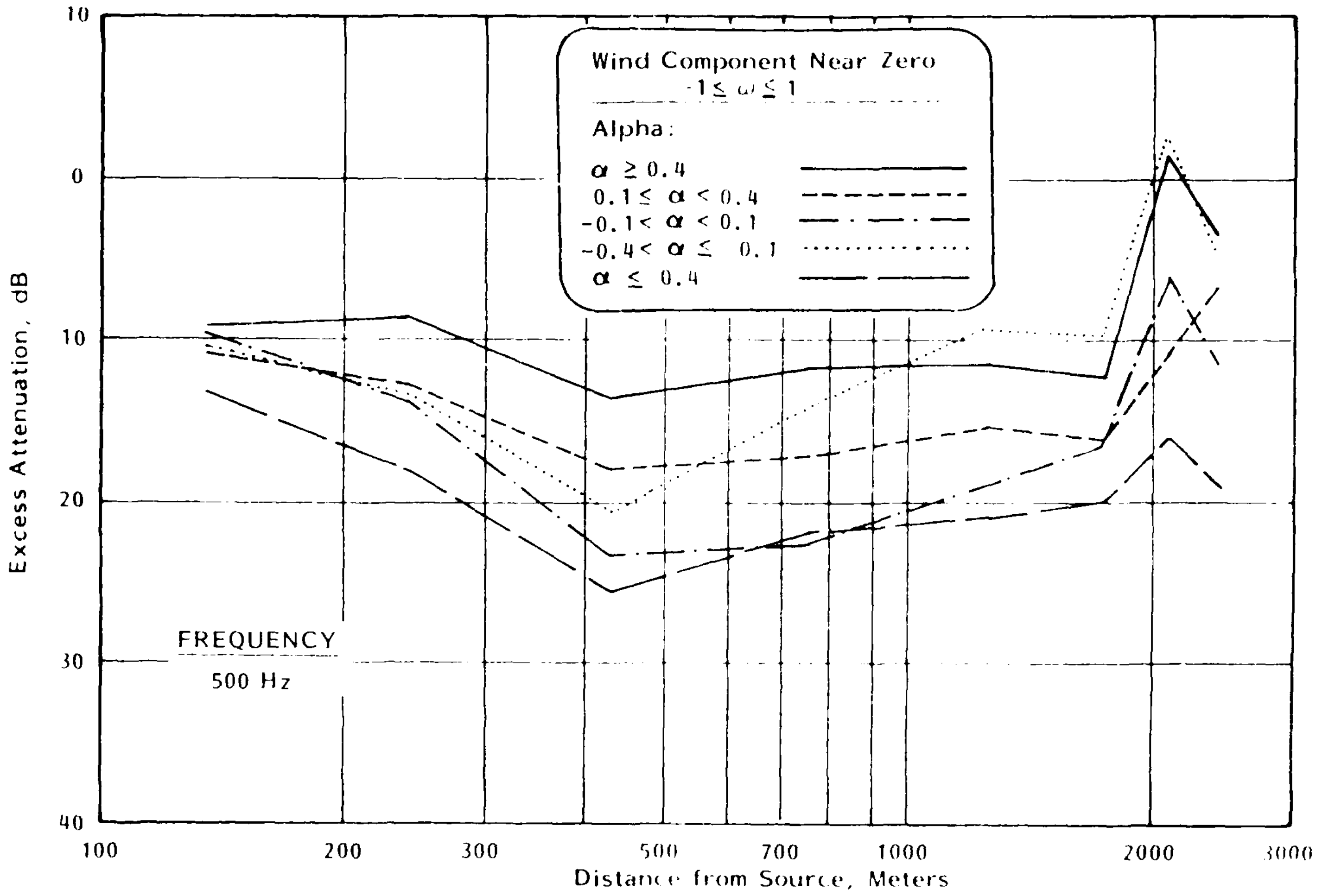

FIGURE 20 E. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS 500 Hz ONE THIRD OCTAVE FREQUENCY BAND

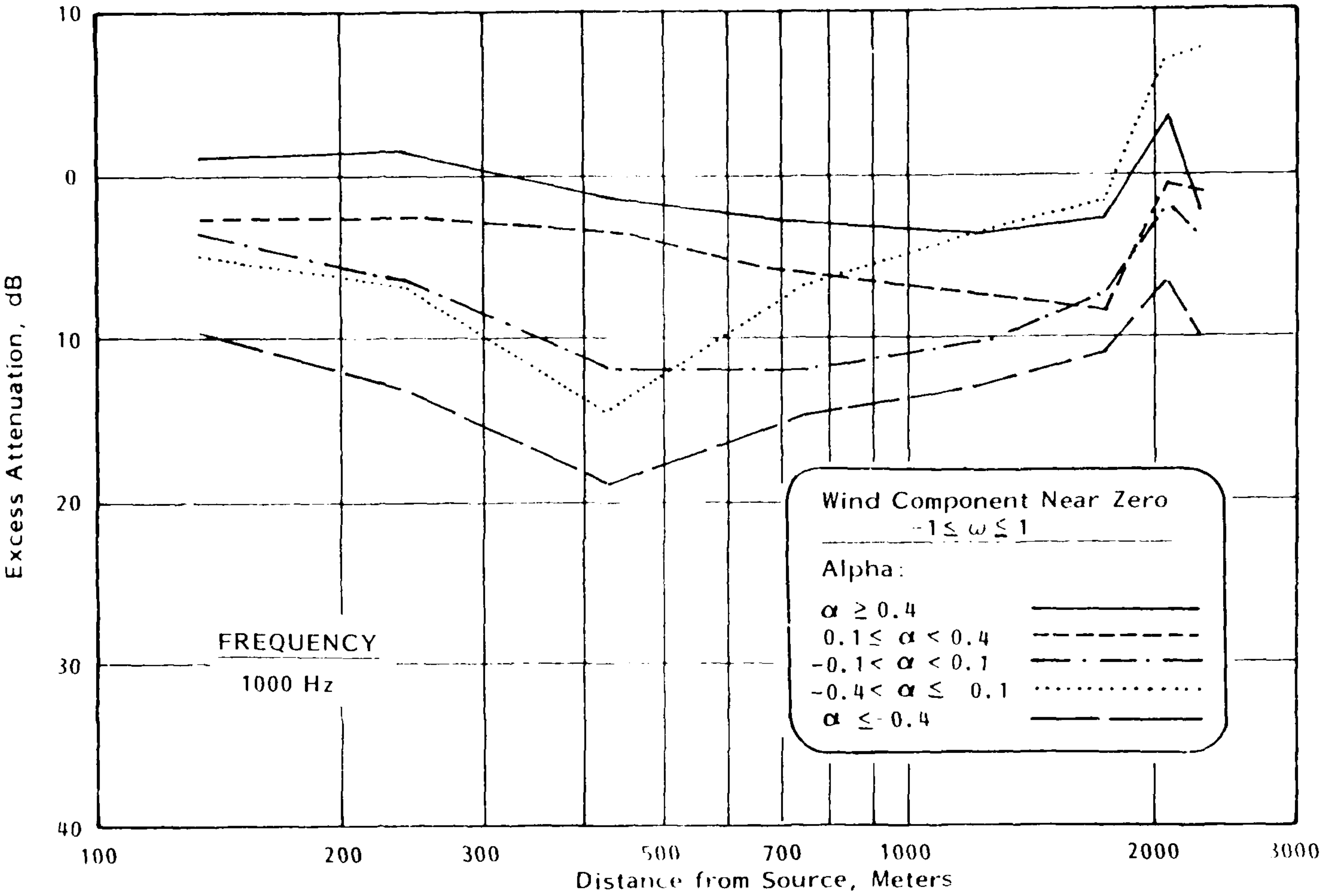

FIGURE 20 F. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS 1000 Hz ONE THIRD OCTAVE FREQUENCY BAND

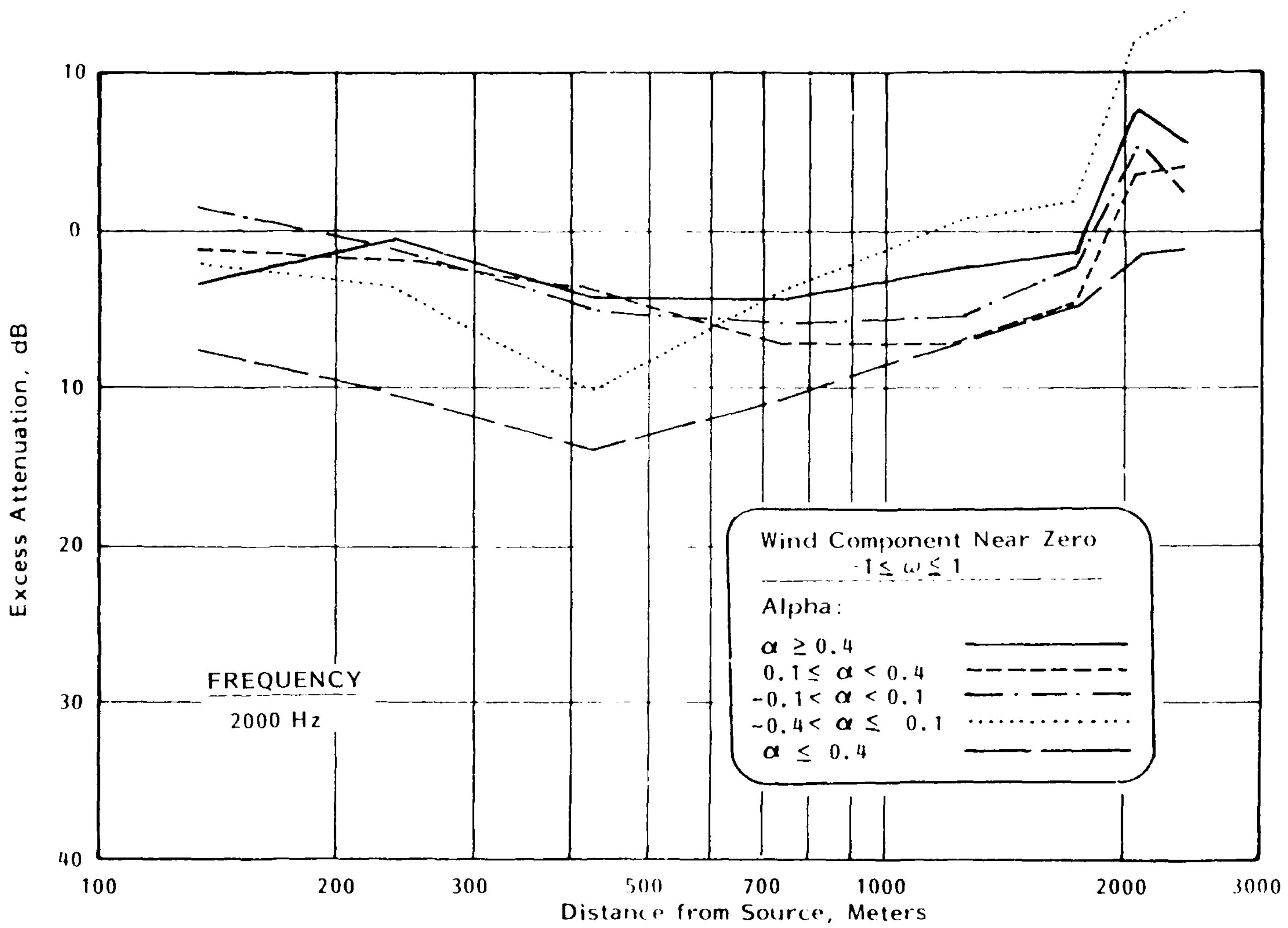

FIGURE 20 G. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS 2000 Hz ONE THIRD OCTAVE FREQUENCY BAND

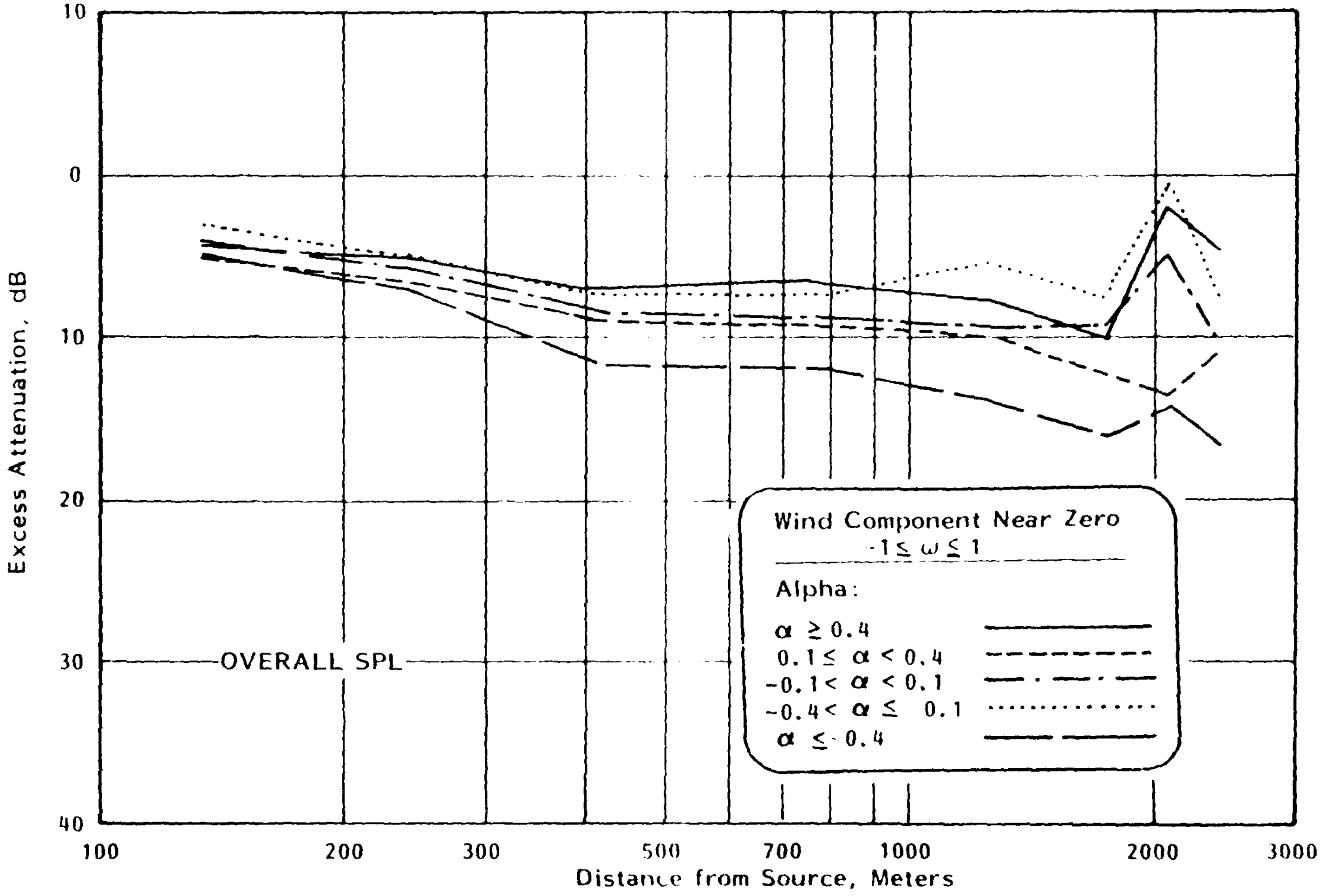

FIGURE 20 H. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS OVERALL SOUND PRESSURE LEVEL

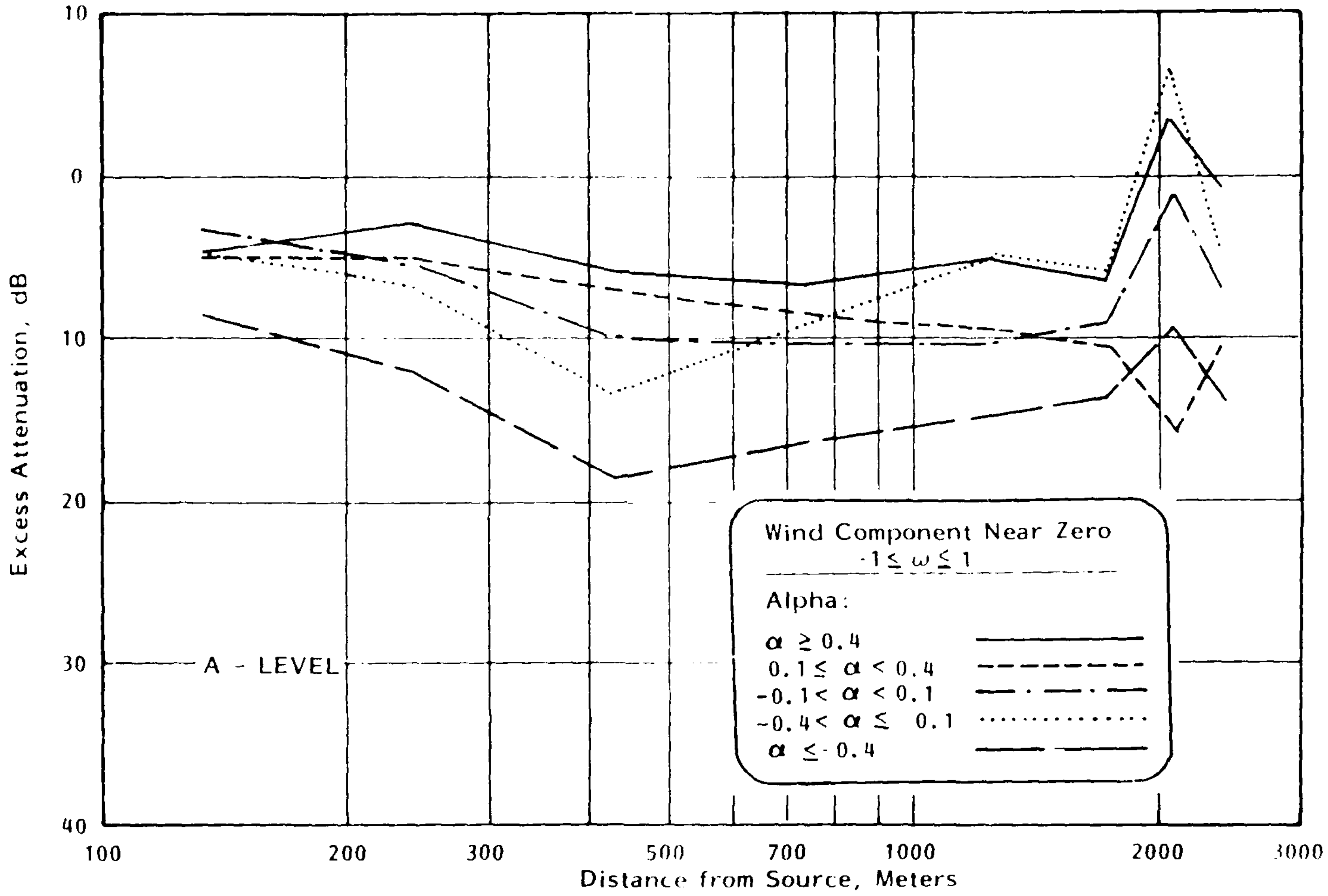

FIGURE 20 1. VARIATION IN EXCESS ATTENUATION WITH TEMPERATURE GRADIENT FOR LOW WIND COMPONENT CONDITIONS A LEVEL as a function of distance. Curves are also shown for the overall and A-weighted sound levels.

Review of Figures 17 through 20 shows that the sensitivity of ESA values to wind component and alpha consistency varies considerably with frequency and, to a lesser extent, with distance. Review also indicates that the sensitivity of ESA to wind component changes is greater than to alpha changes. A simplified comparison of the relative effect of ESA changes with wind component and alpha is shown in Figures 21 and 22. Figure 21 shows the range in ESA values between the -4 and +4 m/s wind component conditions, referred to the ESA for zero wind component. Ranges are shown for three distances. Similarly, Figure 22 shows the range in ESA values for the -0.6 and +0.5 alpha values compared to that for near zero alpha conditions. Comparison of the two figures clearly indicates the greater range in ESA values that were observed for the range of wind component values. Also to be noted is the generally moderate effect of either wind component or temperature gradient values on ESA values at low frequencies, the reduced influence of both variables in the range from approximately 125 to 300 Hz and the generally greatest effect of these variables at the higher frequencies.

Except under conditions of high negative wind (strong upwind conditions) and strong negative temperature gradients, all of the curves show a pronounced maximum in ESA values in the vicinity of 250 Hz. The frequency and the magnitude of the maximum value is relatively little affected by the wind and temperature conditions. This might be anticipated since this maximum occurs at the range where small values of r^2 were observed in the regression analysis. The magnitude of the peak increases with distance from the order of 13 to 18 dB at 134 meters to the order of 20 to 36 dB at larger distances. Generally there is little change in the magnitude of the maximum for distances beyond about 400 meters.

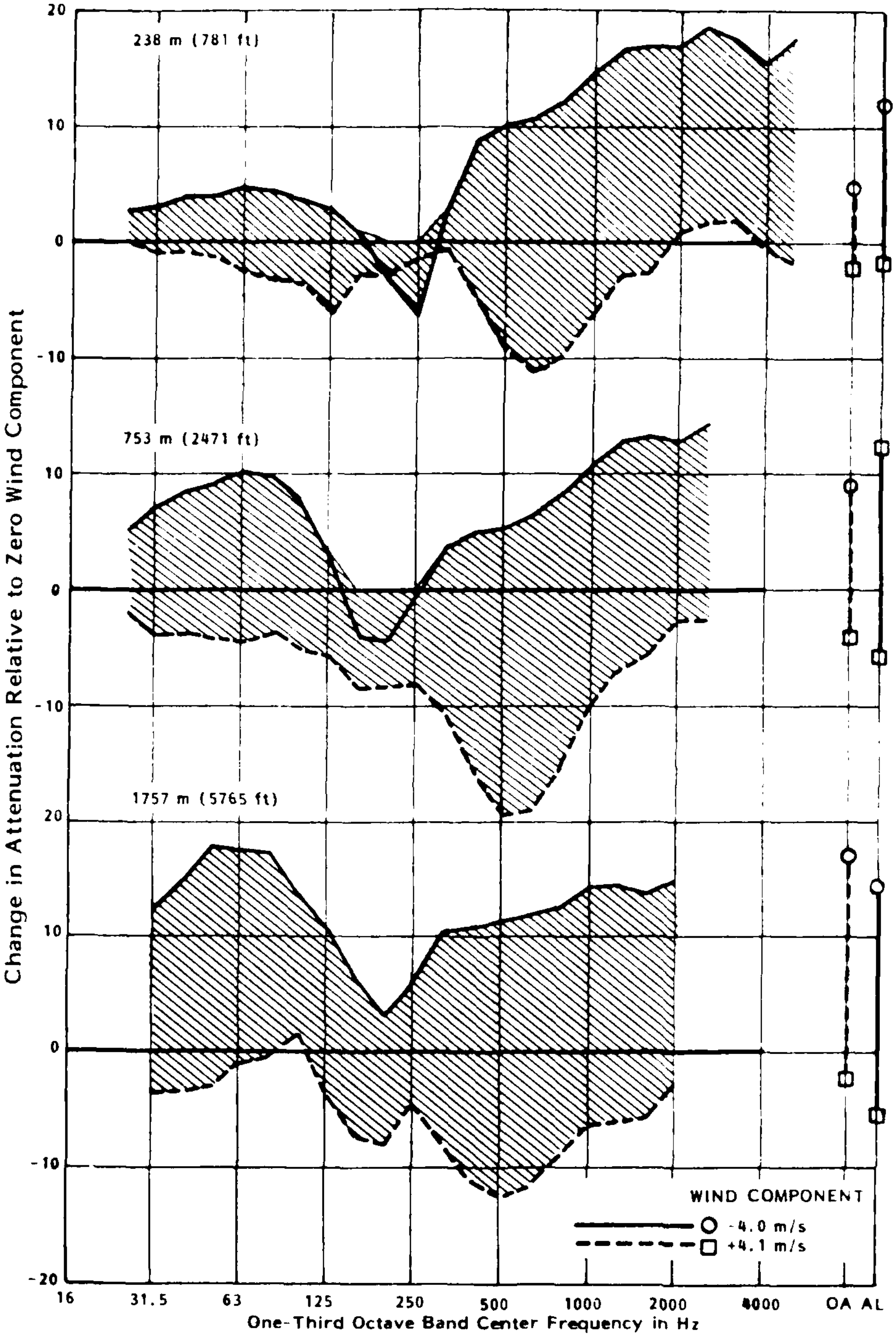

FIGURE 21. INCREASE IN ATTENUATION FOR PLUS AND MINUS 4 M/SEC WIND COMPONENT CONDITIONS REFERRED TO ZERO WIND COMPONENT CONDITIONS (NEUTRAL TEMPERATURE GRADIENT)

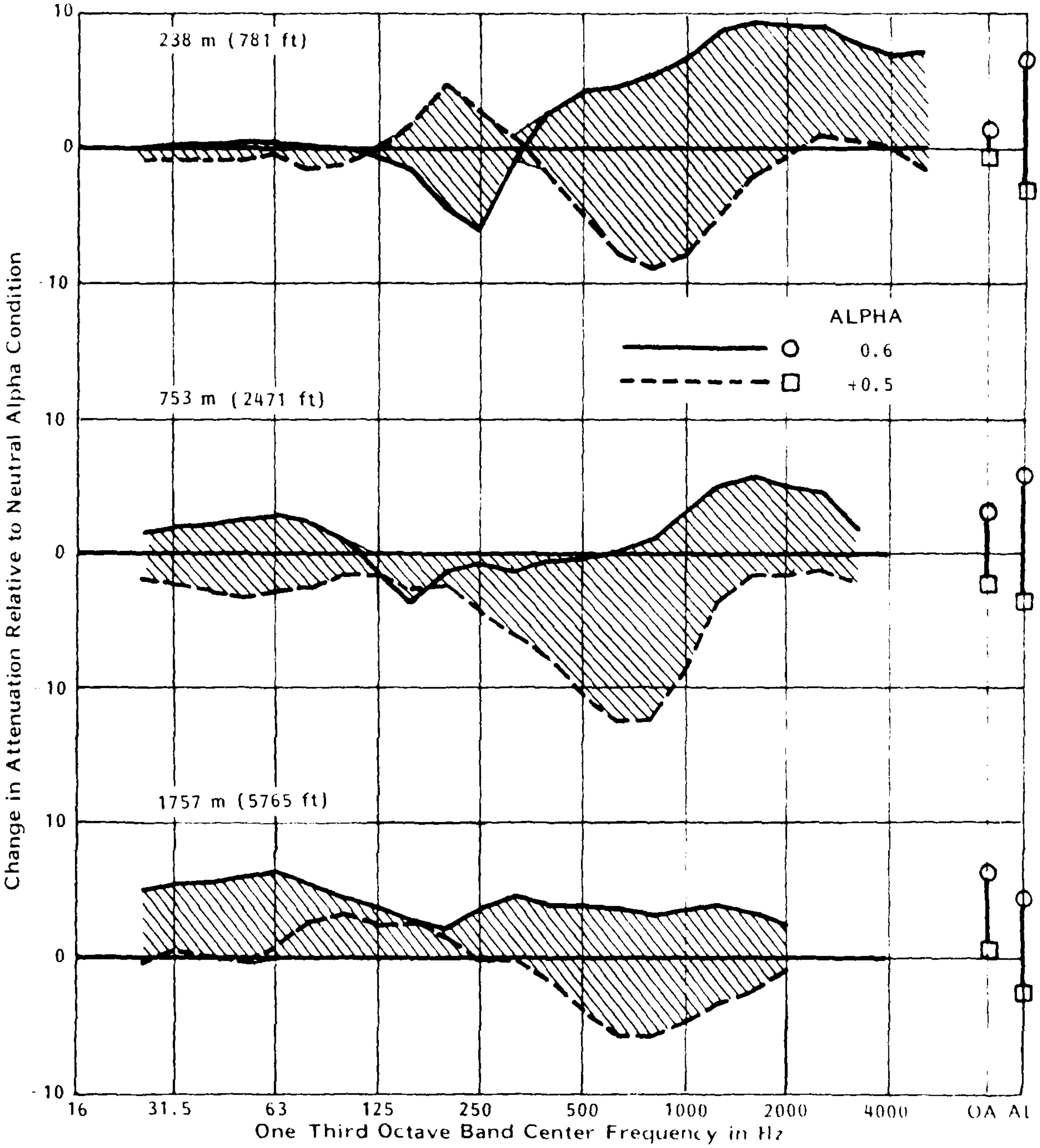

FIGURE 22. INCREASE IN ATTENUATION FOR PLUS AND MINUS TEMPERATURE GRADIENTS REFERRED TO NEUTRAL TEMPERATURE CONDITIONS (ZERO WIND COMPONENT)

In the frequency range below the maximum (typically 25 to 100 Hz) the attenuation generally shows a well ordered dependence on the wind component and temperature gradient. For zero or positive wind component values, attenuations are very small to moderate in magnitude. With negative wind component values, there are generally sharply increasing values of attenuation. The sensitivity of attenuation with temperature gradient in this range is relatively small but does show a trend towards greater attenuation with negative temperature gradients at larger distances.

In the frequency range immediately above the maximum (typically from 300 to 800 Hz) there is a wide variation in ESA depending on wind component or temperature gradient conditions, although the magnitude of ESA values will be less than observed at the maximum. ESA values can vary with wind conditions over the range exceeding 20 dB in this frequency range. Maximum variation due to temperature gradients is of lesser order, typically 10 to 12 dB.

In the higher frequency range (1000 to 2000 Hz and higher) there is continued generally high variability in ESA values with wind component values. As noted previously, the maximum values may be close to those occurring in the 250 Hz frequency range. There is smaller variation of ESA values with positive wind component values than with the negative values (see Figure 21). In this frequency range there is also considerable variation with the temperature gradient although the variation is less than observed for the wind component variation. Absolute ESA values decrease generally as a function of frequency except under the high negative wind component (shadow zone) conditions. In this frequency range the ESA values show a consistent decrease with increasing frequency for all values of temperature gradients.

5.0 COMPARISONS WITH OTHER STUDIES

5.1 Comparison with Parkin and Scholes Field Studies

Probably the measurement studies most directly comparable with the present study are those undertaken by Parkin and Scholes, (References 3, 4 and 5) beginning in 1959 and extending into the early 1960's. In these studies, a jet engine was used as the noise source, with measurements taken out to a distance of 1097 m (3600 ft) from the source. Measurements were taken at two sites (Radlett and Hatfield), along traverses over mostly near-level grassland parallel to airport runways. The source engine exhaust centerline was approximately six feet above the ground and measurements were taken at a height of five feet above the ground with noise levels averaged over a five to ten minute period per set of measurements. The noise was measured along a line approximately 45° to the jet axis assuming the sound source center was located six feet aft of the plane of the engine exhaust. The reference measurement position was located much closer to the source than in the current study, at a distance of 19.5 m (64 ft.)

The noise data were analyzed and reported in one-third octave frequency bands. Wind direction and magnitude were measured and excess attenuation compared as a function of the wind component. Temperature gradient measurements were less complete, hence it is not possible to match ESA data closely for the same temperature gradient conditions.

Comparisons with the Parkin and Scholes results are shown in Figures 23 through 27. Comparisons are given for a distance of 195 m (640 ft) and for the farthest distance measured by Parkin and Scholes, 1097 m (3600 ft).

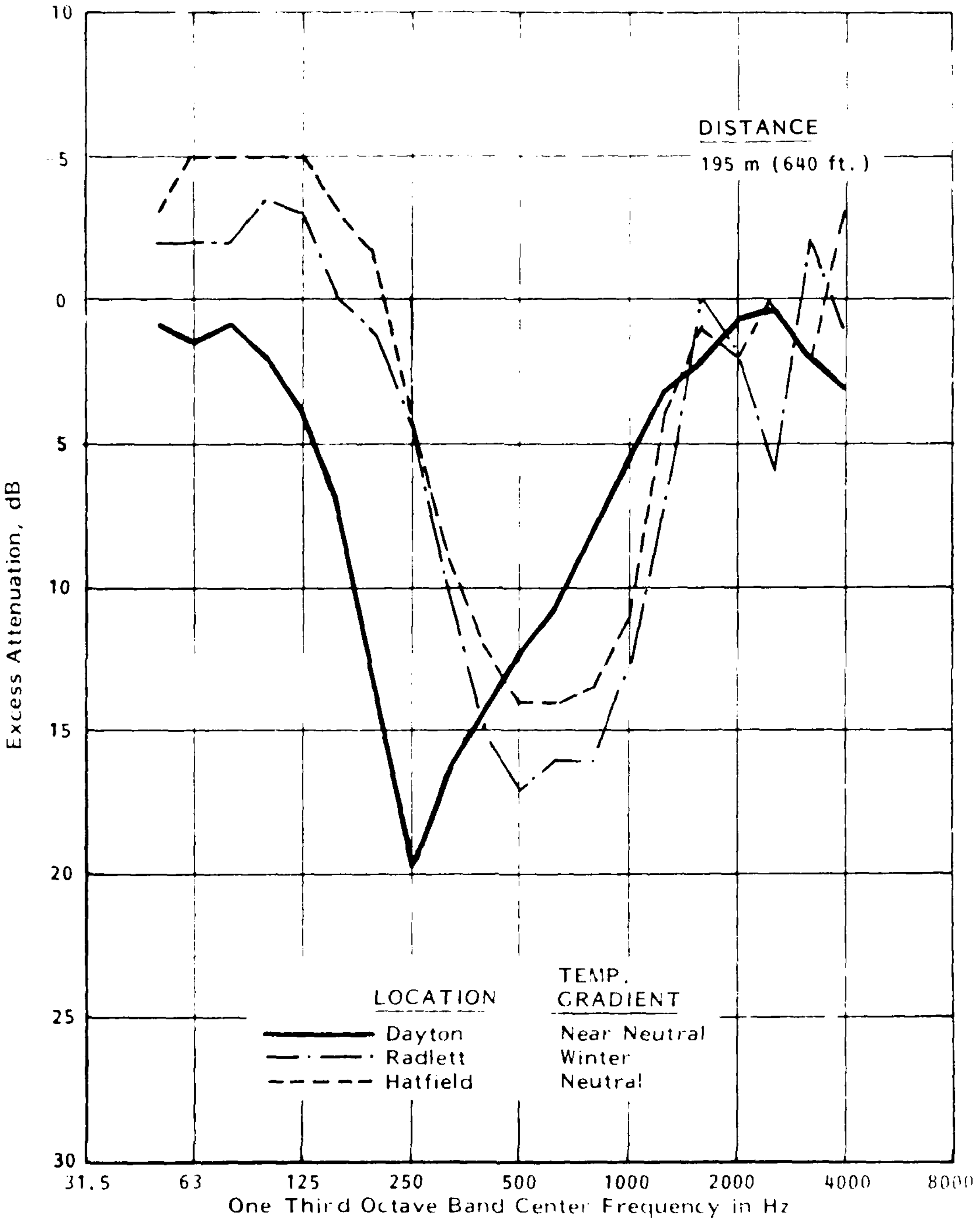

FIGURE 23 A. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES ZERO WIND COMPONENT, NEUTRAL TEMPERATURE GRADIENT

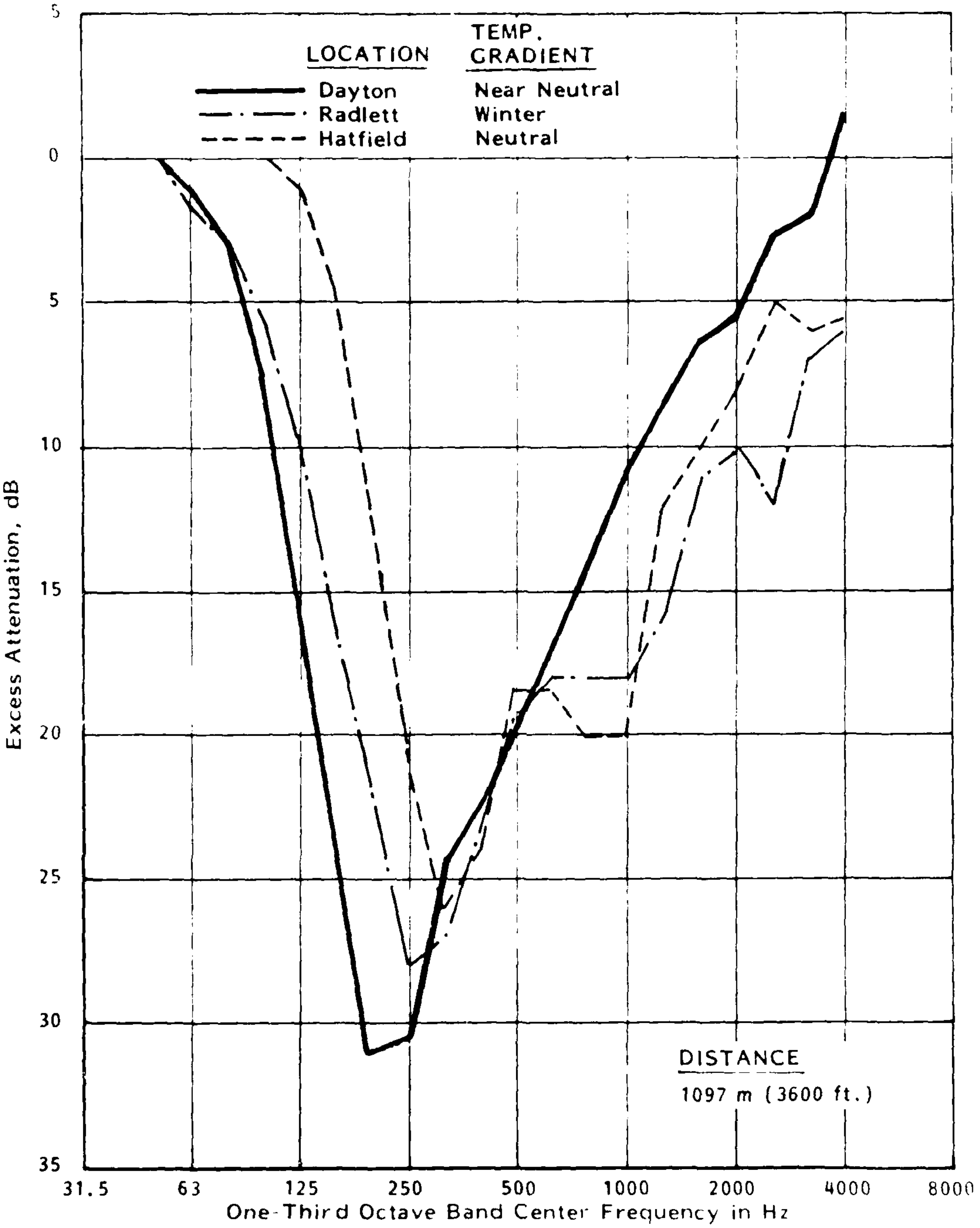

FIGURE 23 B. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES ZERO WIND COMPONENT, NEUTRAL TEMPERATURE GRADIENT

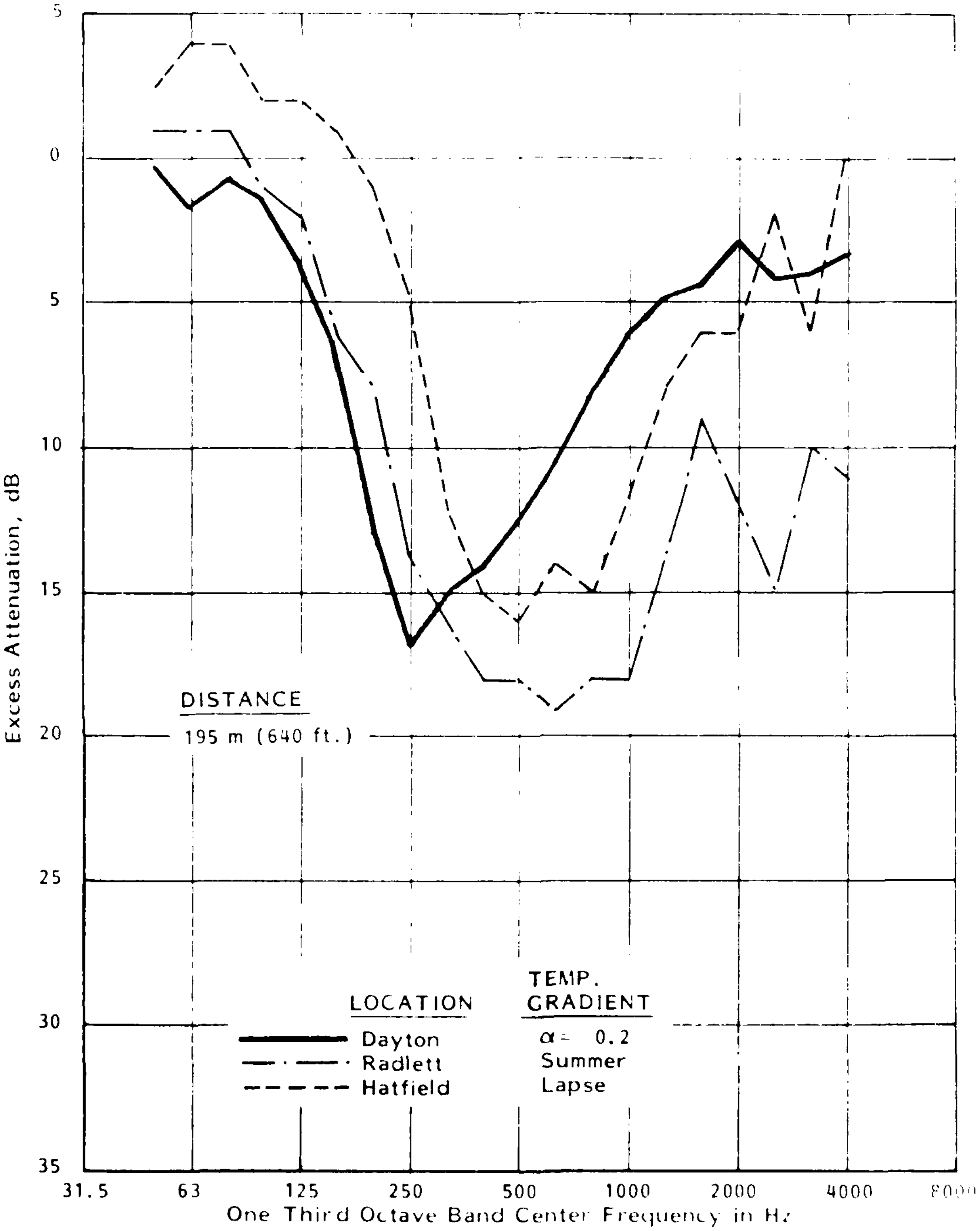

FIGURE 24 A. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES
ZERO WIND COMPONENT, NEGATIVE TEMPERATURE GRADIENT

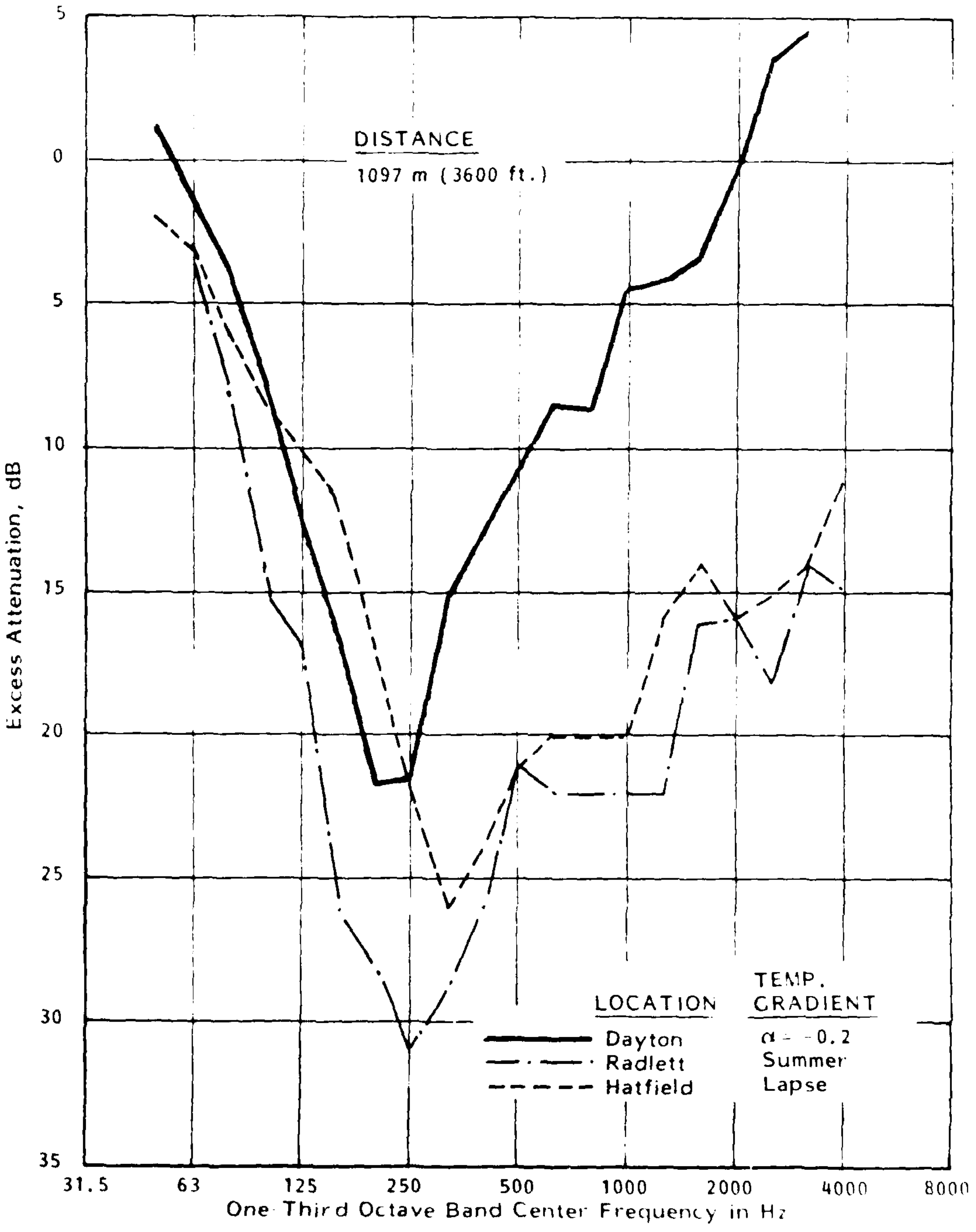

FIGURE 24 B. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES ZERO WIND COMPONENT, NEGATIVE TEMPERATURE GRADIENT

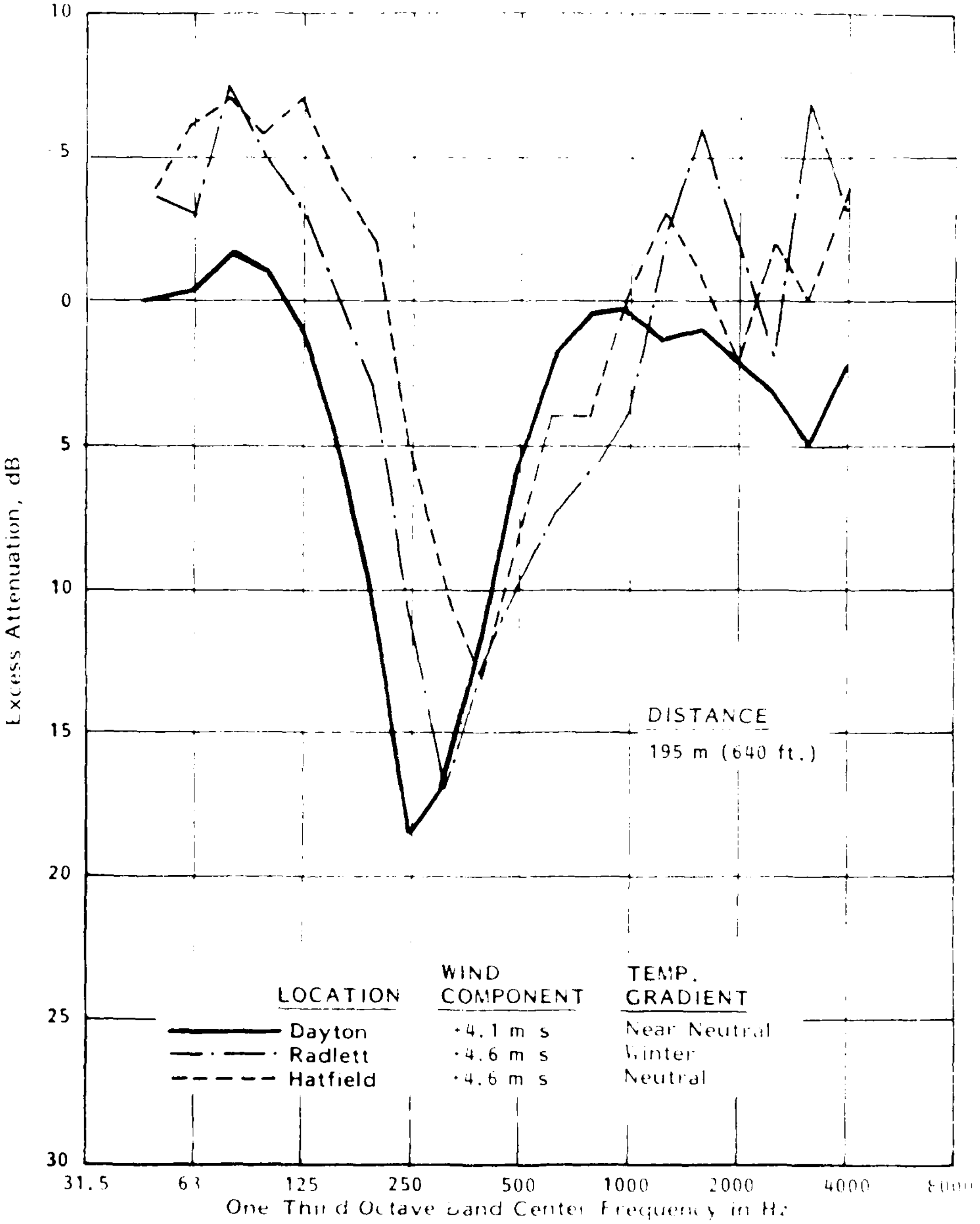

FIGURE 25 A. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES POSITIVE WIND COMPONENT, NEUTRAL TEMPERATURE GRADIENT

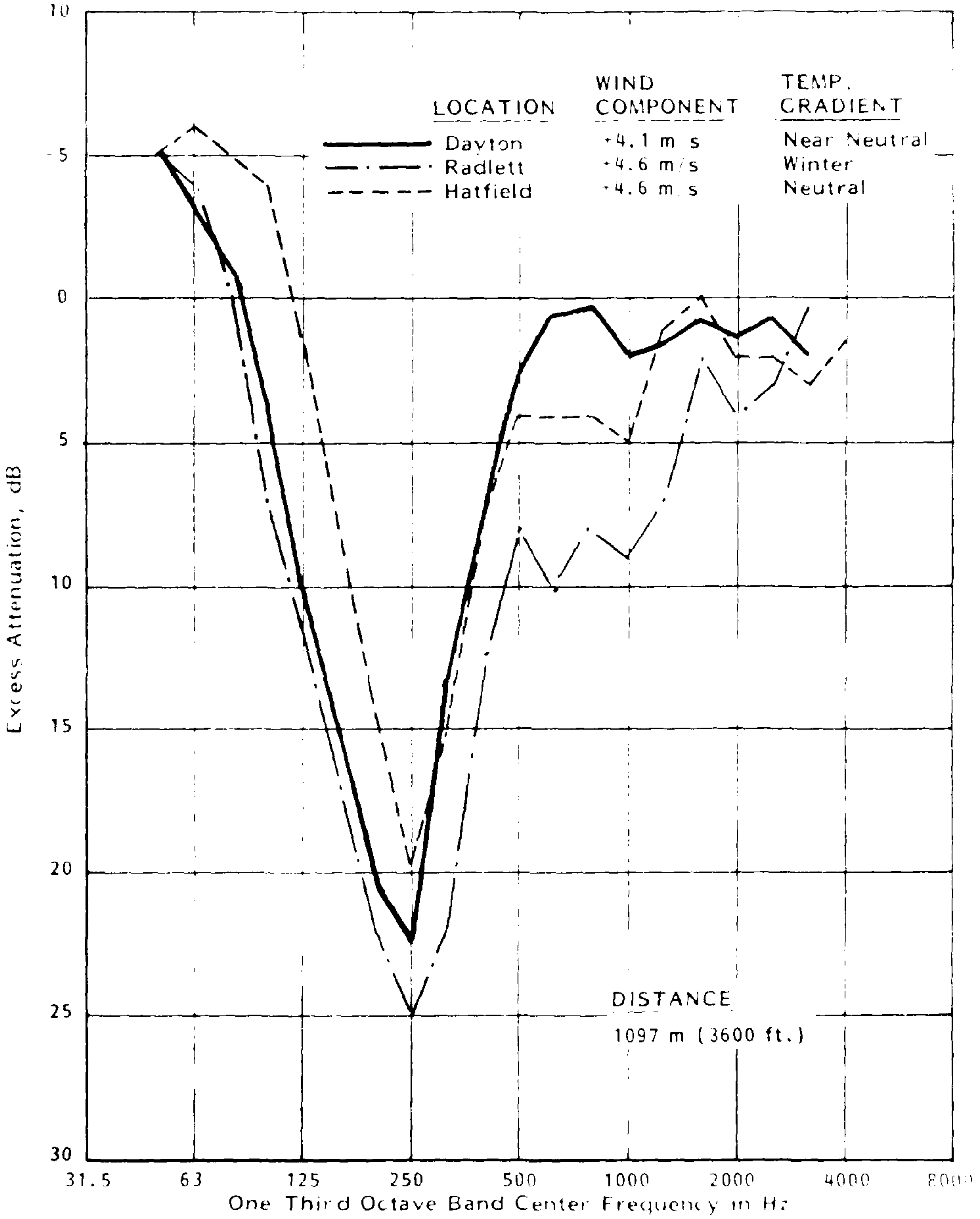

FIGURE 25 B. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES POSITIVE WIND COMPONENT, NEUTRAL TEMPERATURE GRADIENT

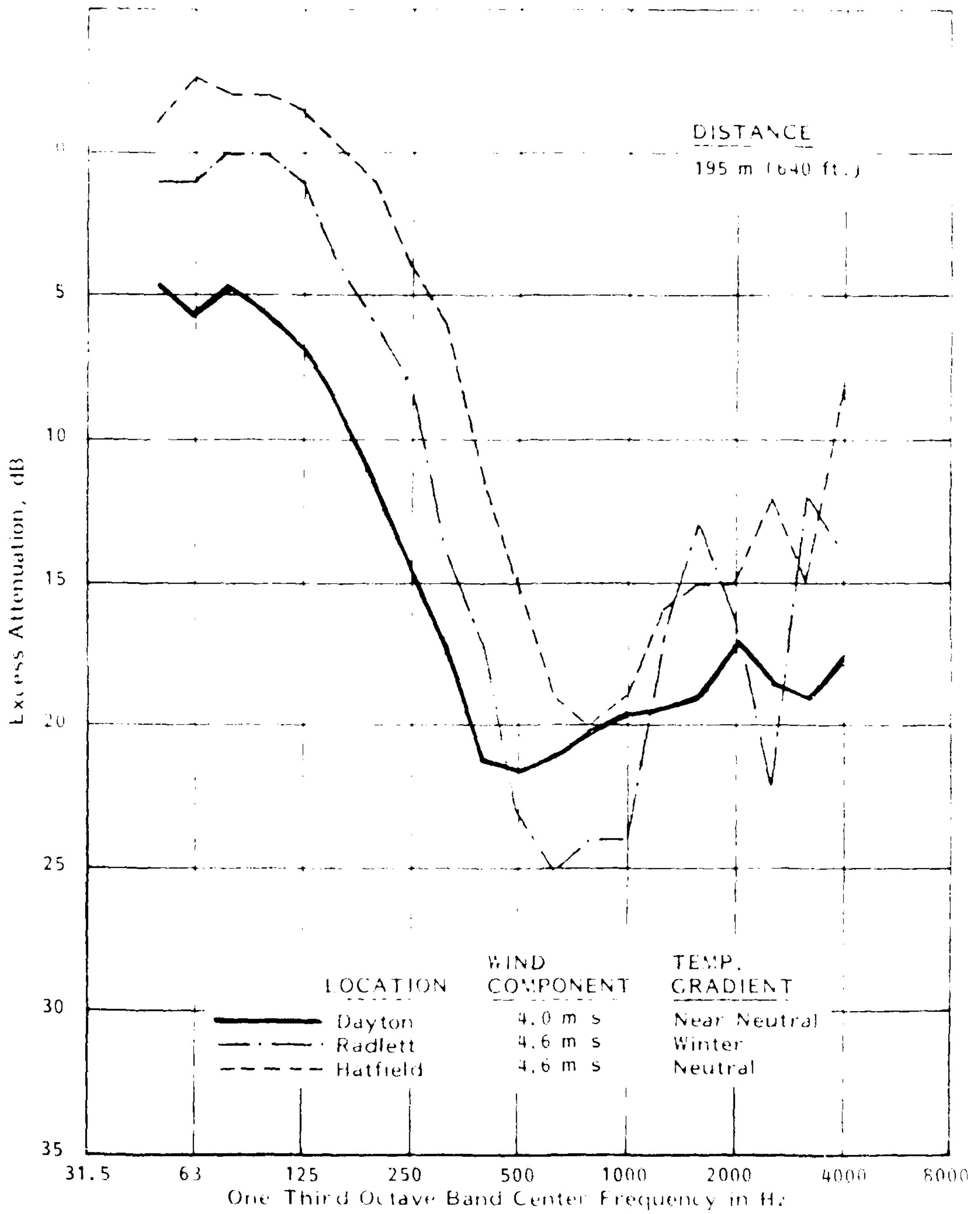

FIGURE 26 A. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES
NEGATIVE WIND COMPONENT, NEUTRAL TEMPERATURE GRADIENT

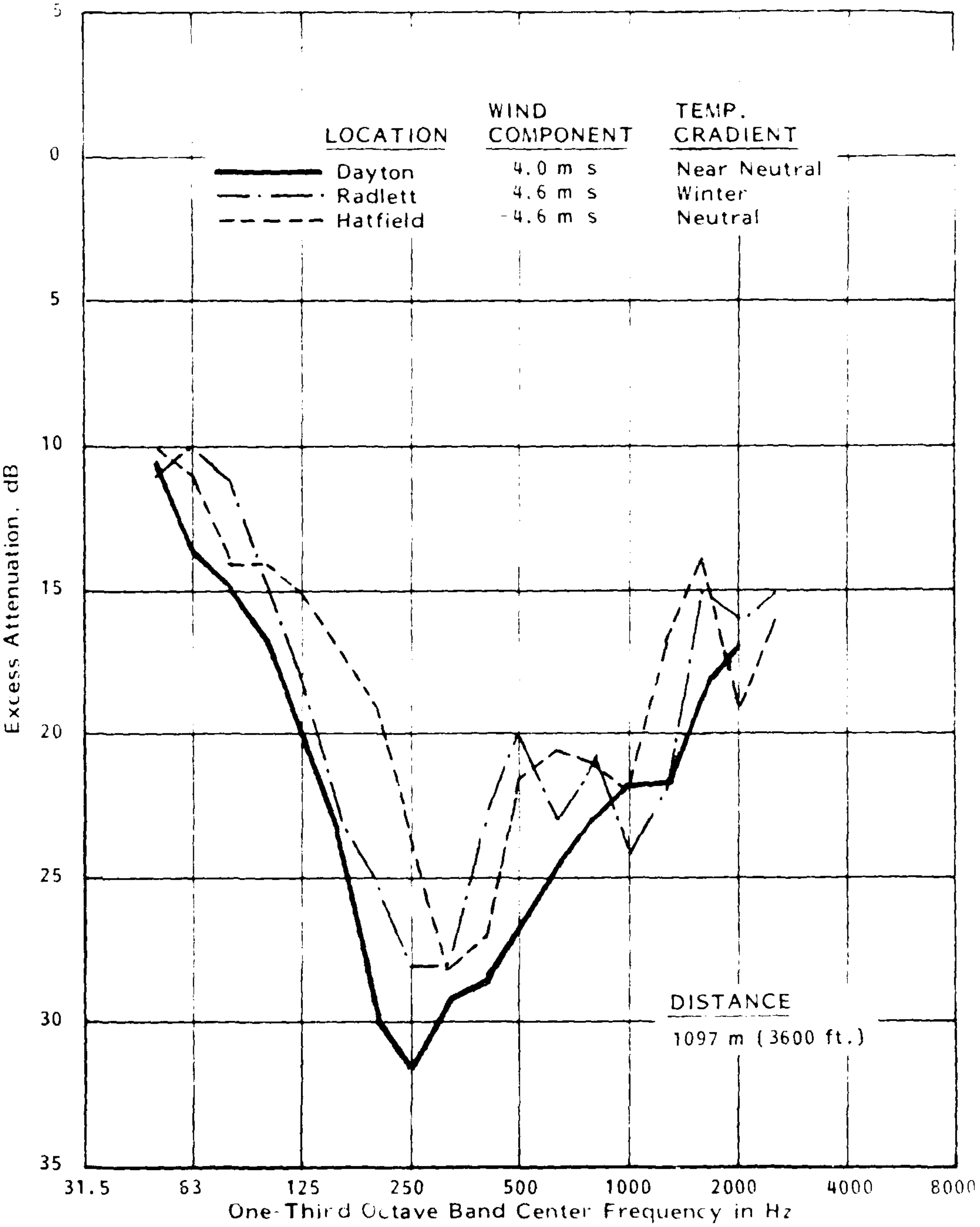

FIGURE 26 B. COMPARISON OF MEASURED ATTENUATION AT DIFFERENT SITES NEGATIVE WIND COMPONENT, NEUTRAL TEMPERATURE GRADIENT

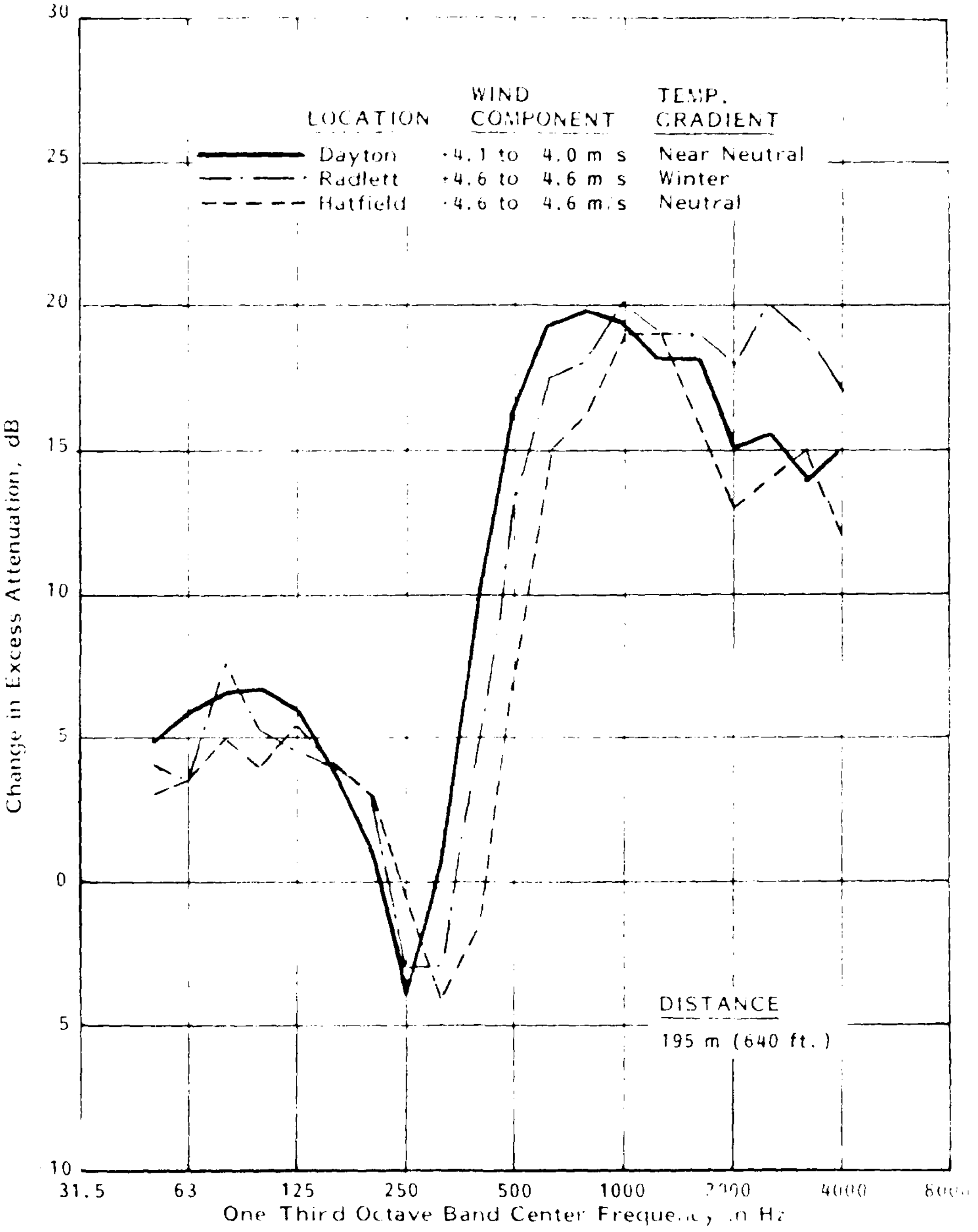

FIGURE 27 A. COMPARISON OF CHANGES IN EXCESS ATTENUATION WITH WIND COMPONENT

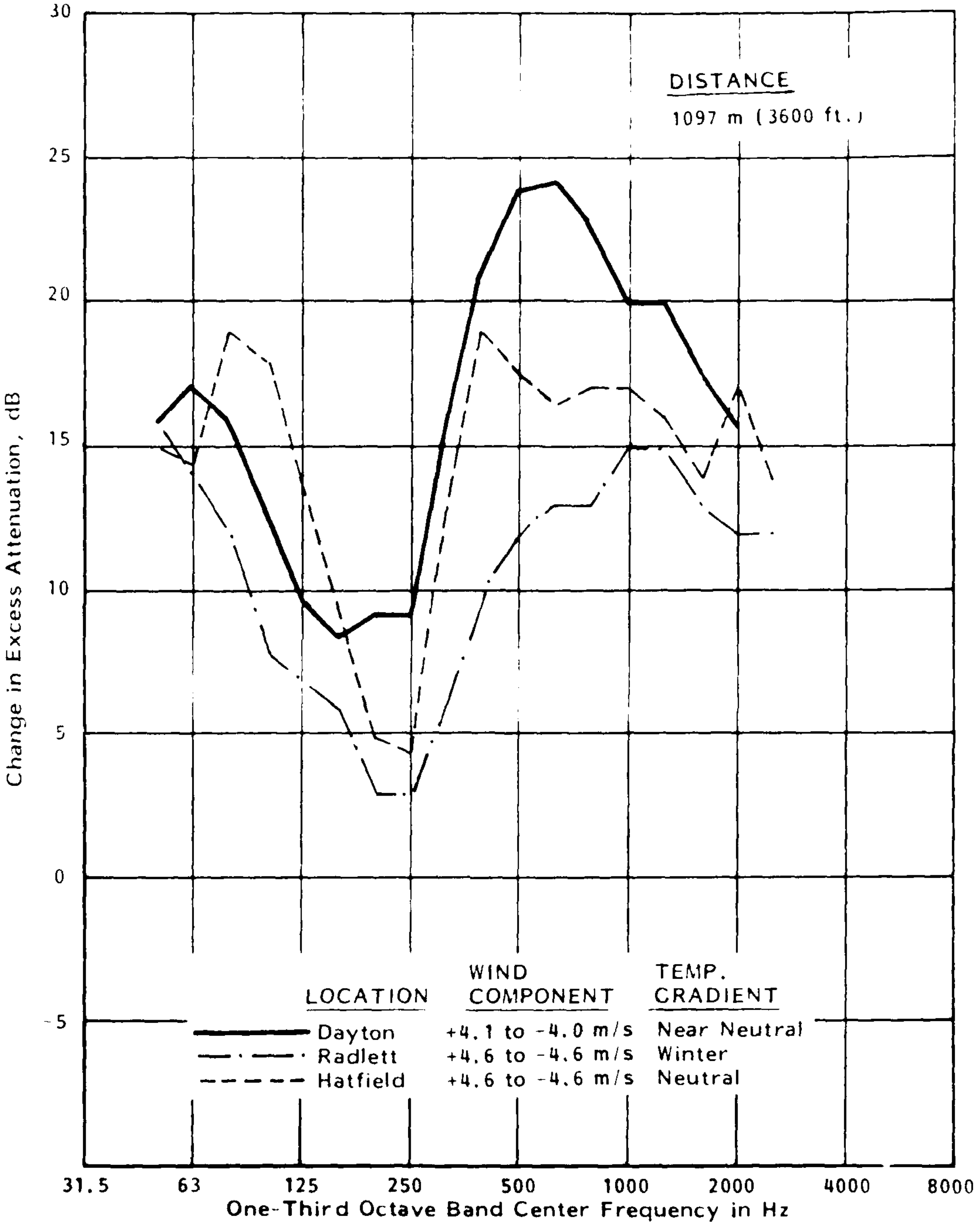

FIGURE 27 B. COMPARISON OF CHANGES IN EXCESS ATTENUATION WITH WIND COMPONENT

Because measurement locations were not the same in the studies, ESA values measured at the two positions adjacent to the specified Parkin and Scholes positions have been averaged to represent the levels for the current study at the comparable Parkin and Scholes position. The averaging was done on a log distance basis.

One difference in the reporting of data should be noted. This study reports averages of data within a given range of meteorological conditions. The Parkin and Scholes excess attenuation values were reported on the basis of a smooth curve drawn through the measured data plotted against wind component, with values read off at specified wind component values.

Another important difference to be kept in mind in comparing data is the large difference in choice of reference microphone positions. Because of the close-in position chosen by Parkin and Scholes, their reported excess attenuation values are likely to include more of the "total" excess attenuation between source and more distant measuring positions.*

Figure 23 compares the Hatfield and Radlett ESA values with current measurements (labeled Dayton) for two distances, 195 m (340 ft) and 1079 m (3600 ft). The figure is for zero wind component conditions, and near neutral temperature gradient (taken as the winter measurements for the Radlett measurements). The general shape of the curves as a function of frequency is quite similar although the Dayton measurements present a sharper curve with the maximum occurring at a lower frequency, more closely matching the Radlett data. Figure 24 again shows the measurements for zero wind component conditions and a small negative temperature gradient (using "lapse" data for Hatfield and summer data for Radlett). The Dayton measurements again show a sharper maximum with significantly less attenuation above the maximum values. As in Figure 23, the low frequency portion of the Radlett data generally provides a closer fit to the Dayton data than do the Hatfield results. Comparison of Figures 23 and 24 shows that the frequencies at which the maximums occur for the Dayton measurements show a somewhat smaller shift with distance than do the Parkin and Scholes data.

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*The measurements at close-in position probably were not in the "far field" of the engine source, possibly introducing some error in assuming inverse square reduction in determining ESA values.

Figures 25 and 26 compare the measurements under near-neutral temperature conditions with plus and minus wind component values. Figure 25, for positive wind component data, shows curve shapes that are very similar with all data showing a relatively sharp maximum. For the closer distance, the Dayton data show a lower frequency for the maximum than either the Radlett or Hatfield measurements. For large distances, the Dayton data matches the Hatfield data quite closely.

Figure 26, presenting data for negative wind component conditions, again shows curve shapes that are similar in character with relatively broad dips to the negative wind component. Again the general tendency is for the maximum of the Dayton data to occur at or below the frequencies for the Parkin and Scholes measurements.

One further comparison is given in Figure 27. This figure shows the shift in attenuation values from a minus to a plus wind component situation for near-neutral temperature conditions. At the closer distance (195 m) there is very good agreement in data among the three sets of measurements with all curves showing similar trends as a function of frequency. At the larger distance (1096 m) the curves diverge in shape and in magnitude, with the Dayton data showing a generally greater change with wind component at frequencies above about 250 Hz.

The general trend of the Dayton data is, thus, in general agreement with the Parkin and Scholes measurements with very small differences. The frequency at which maximum attenuation occurred in the Dayton data is usually lower than shown by either the Hatfield or Radlett data.

5.2 Comparison With 1967 Airport Measurement Study

The NOISEMAP program currently uses sets of frequency- and distance-dependent curves for calculating excess attenuation which are based on field measurements of excess attenuation made during the takeoff roll of jet aircraft at two civil airports--Los Angeles International and Denver Stapleton airports (Reference 8). The 1967 measurements were made along lines extending approximately 45 degrees to the engine exhaust (at the start of takeoff roll), thus most measurements were made under downwind conditions (positive wind component values).

The field conditions for these measurements were distinctly different from the Dayton measurements in several important respects. Although the ground was generally level, the terrain variations were greater than for the current measurements. In addition, most measurements were made in developed community areas hence there were many buildings and other obstacles that blocked the line-of-sight between the aircraft or aircraft reference microphone and the most distant measuring positions. The surfaces also varied significantly in terms of impedance, because they included sections of grassland, concrete, asphalt and other surfaces. In addition, local meteorological conditions were not as carefully measured as in the Dayton program.

The curves from the 1967 studies have been used in NOISEMAP since these curves had been obtained under "realistic" field conditions which included the effects of intervening buildings between the aircraft source and the receiver, which is typical of many airport/community situations. The curves were based on an average of data for which the wind speed was greater than five m/s (for these data, the average wind component magnitude was approximately 3.4 m/s). The reference measurement position varied from 46 to 180 meters from the aircraft and measurements were made out to a maximum distance of 2,770 meters. In the analysis, data were grouped into three distance ranges having mean distances from the aircraft source of 792 m, 1585 m and 2133 m.

In Figure 25, the average excess attenuations reported in the 1967 study for wind speeds greater than five m/s are compared with the Dayton data at the nearest comparable measurement distance for conditions with average wind component values of 1.7 and 4.1 m/s with near-neutral temperature gradients.*

The curves for the 1967 study show much greater excess attenuation at the lower frequencies of 31.5 and 63 Hz bands at all distances. At the closest distance (792 m for the 1967 study), the 1967 curve shows comparable excess attenuation at 125 Hz and much less attenuation at higher frequencies. At the larger distances, the 1967 curves show greater attenuation at 125 Hz, comparable attenuation at 250 Hz, and, at the higher frequencies of 500 and 1000 Hz, show generally comparable or slightly more attenuation than the current measurements.

The 1967 measurements show maximum excess attenuation in the vicinity of 125 Hz compared to the order of 250 Hz in the current measurements. The earlier curves also show a very broad maxima compared to the sharper maxima observed in the current measurements. Much of this is due, of course, to the fact that in the 1967 study, measurements were analyzed in octave bands rather than

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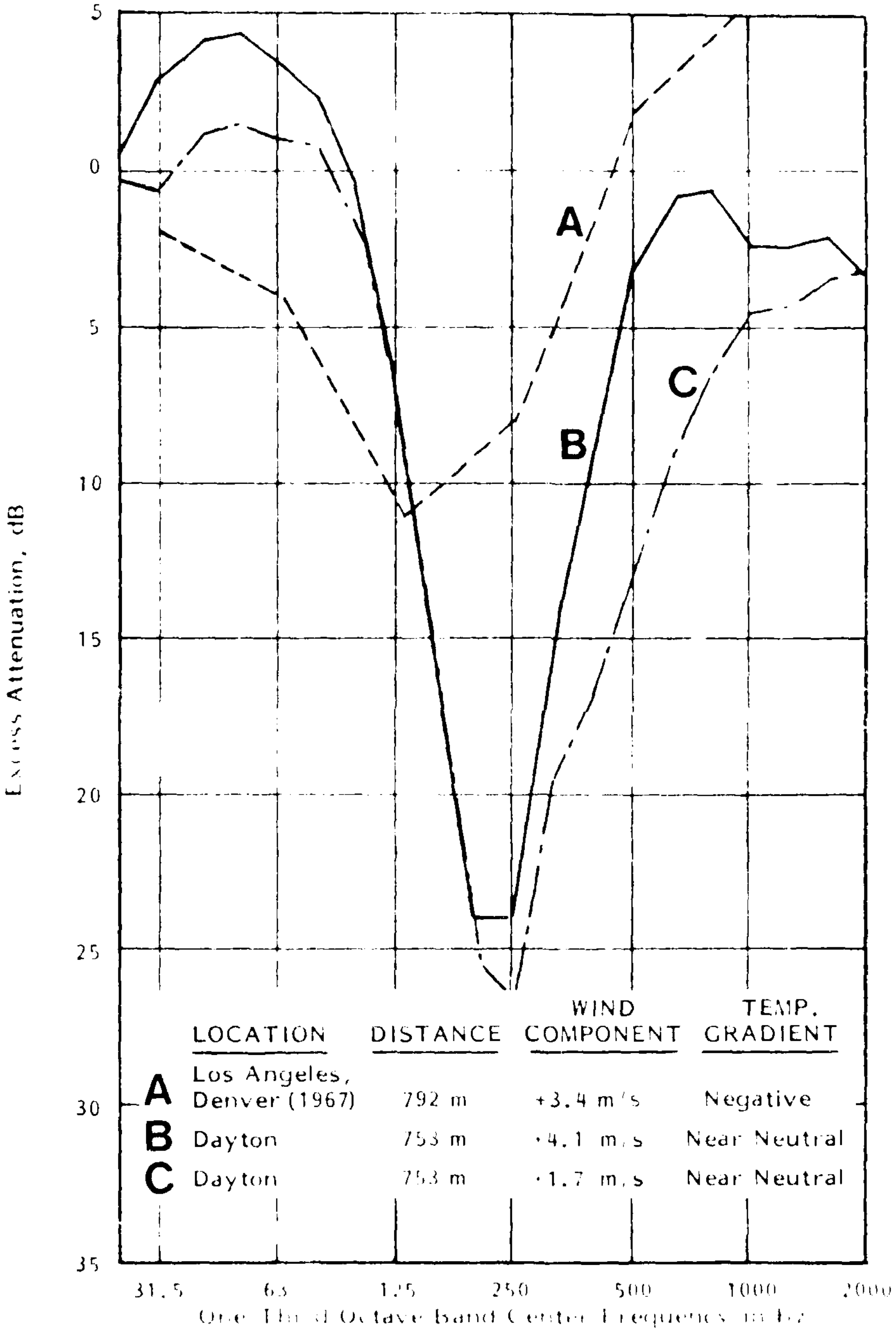
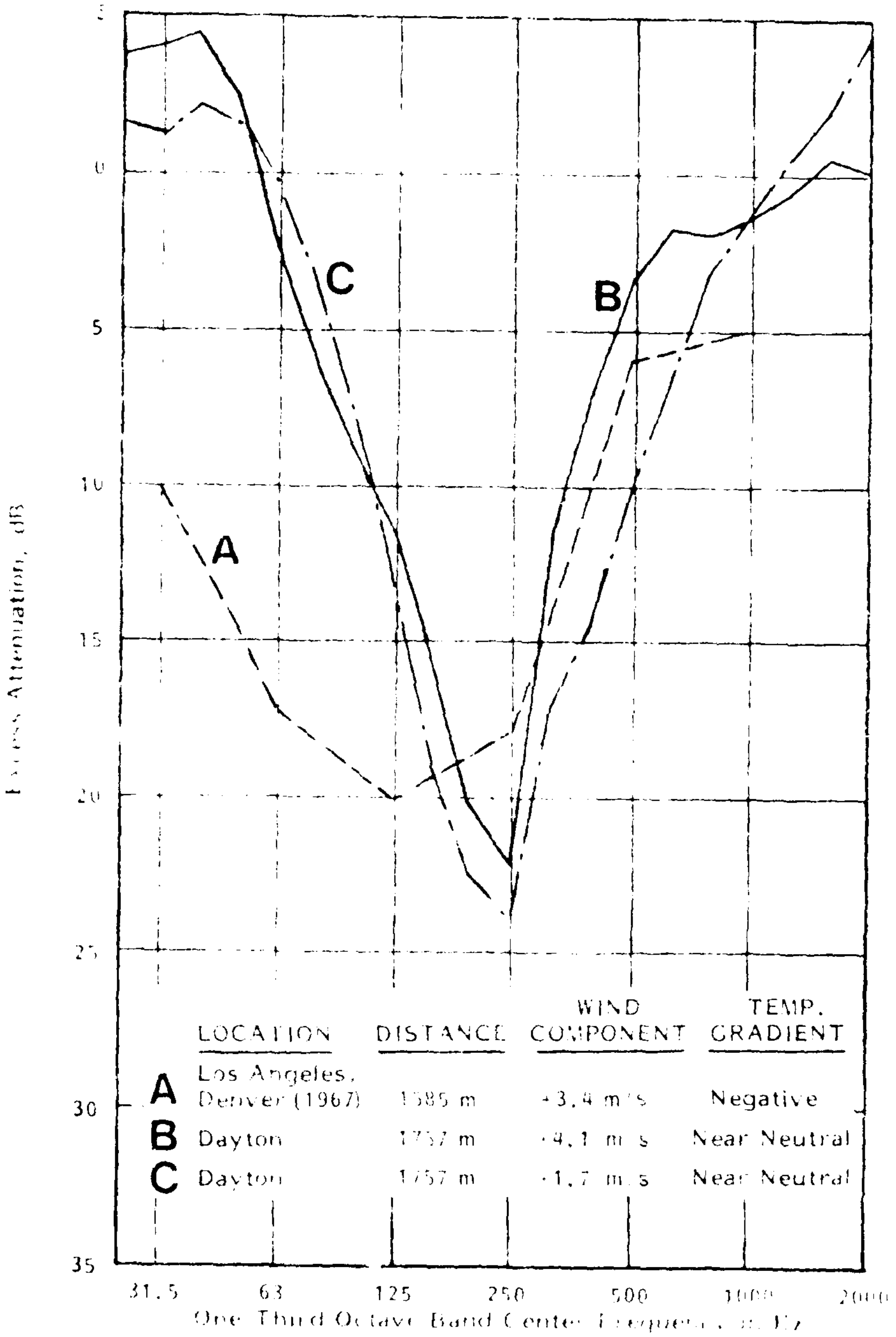
*Most of the 1967 study data were obtained under negative temperature gradient conditions.



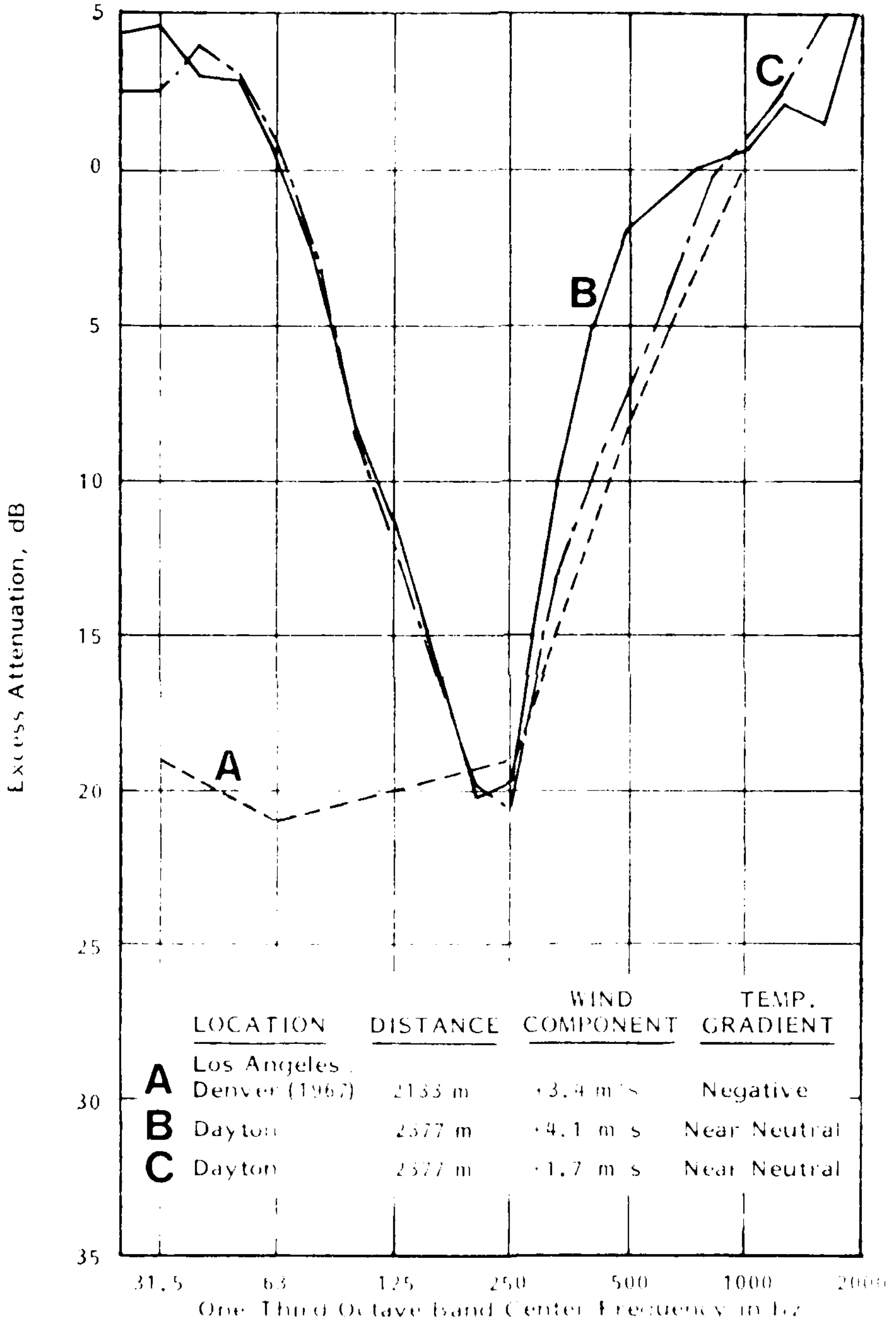
	LOCATION	DISTANCE	WIND COMPONENT	TEMP. GRADIENT
A	Los Angeles, Denver (1967)	792 m	+3.4 m/s	Negative
B	Dayton	753 m	+4.1 m/s	Near Neutral
C	Dayton	753 m	+1.7 m/s	Near Neutral

FIGURE 28 A. COMPARISON OF MEASURED ATTENUATION WITH 1967 AIRPORT MEASUREMENTS



	LOCATION	DISTANCE	WIND COMPONENT	TEMP. GRADIENT
A	Los Angeles, Denver (1967)	1585 m	+3,4 m/s	Negative
B	Dayton	1757 m	+4,1 m/s	Near Neutral
C	Dayton	1757 m	+1,7 m/s	Near Neutral

FIGURE 28 B. COMPARISON OF MEASURED ATTENUATION WITH 1967 AIRPORT MEASUREMENTS



	LOCATION	DISTANCE	WIND COMPONENT	TEMP. GRADIENT
A	Los Angeles Denver (1967)	2133 m	+3.4 m/s	Negative
B	Dayton	2377 m	+4.1 m/s	Near Neutral
C	Dayton	2377 m	+1.7 m/s	Near Neutral

FIGURE 28 C. COMPARISON OF MEASURED ATTENUATION WITH 1967 AIRPORT MEASUREMENTS

in one-third octave bands. There may also have been more scattering in the 1967 tests due to the more irregular and diverse surfaces and potentially greater variability in local meteorological conditions.

The reasons for the greater attenuation observed in the 1967 study for the lower frequencies of 31 and 63 Hz are not known. However, the attenuations are probably due, in part, to the shielding and scattering provided by the many obstructions between the source and receivers.

5.3 Comparisons With Theory

The propagation of spherical waves from a point source near a reflecting plane is a complex mathematical problem which has been studied by many, and a number of mathematical models exist.* For this study, the excess sound attenuation under conditions of a near zero temperature gradient and near zero wind component conditions are compared with an analytical model which assumes a uniform atmosphere and a level surface having a finite uniform impedance. The selected analytic model assumes that the ground is a locally reacting surface, and waves within the ground are not considered. Recent work indicates that this model should fit the experimental conditions quite well.

The major model equations are described in Appendix A. The model is that given by Chessell, (Reference 11) with modifications after Attenborough (Reference 12). The introduction of atmospheric turbulence effects follows the work of Daigle (Reference 13). We have assumed that the ground surface can be characterized by an effective flow resistance, with the impedance at different frequencies estimated by equations developed by [illegible]...

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*There has been renewed interest in sound propagation in recent years with much of the recent work summarized in References 4 and 10.

The procedure has been to compare the experimental results at different distances with the model predictions, assuming, on a trial and error basis, different surface impedance values and atmospheric turbulence quantities.

5.3.1 Attenuation Between Source and Reference Microphones

One problem in comparing predictions with field results is the need to allow for the excess attenuation that may have occurred between the source and the reference microphone positions. The geometrical conditions and distances are such that considerable excess attenuation may have occurred between the source and reference positions and is not accounted for in the experimental measurements. A complication is the fact that for even numbered arrays the hard surface between the aircraft and the edge of the grass was 46 m (150 ft) leaving [illegible] m ([illegible] ft) of grass to the reference microphone, while the odd numbered arrays had 61 m (200 ft) of hard surface and only 5 m ([illegible] ft) of grass.* The analytical model indicates a very large difference in the maximum excess attenuations observed in the vicinity of [illegible] Hz occurring between the reference positions and the distant positions dependent upon whether there is a grass or concrete surface between the source and the reference microphones.

Further complications arise from the fact that the reference microphone positions were at different distances from the source for each array and that the reference levels are the energy average of levels measured at two heights at [illegible] and 2.4 m.

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*This accounts for some of the difference between reference spectra measured along different arrays as shown in Figure [illegible].

To allow for the excess attenuation between the source and reference microphone, the approach adopted was to calculate the excess attenuation at the reference microphone positions in a manner closely corresponding to the way the actual noise levels were calculated. Specifically, the excess attenuation for different values of assumed impedance were calculated for each reference microphone distance and for the two microphone heights at each position. The excess attenuations for the two microphones at each position were then added on an energy basis. The arithmetic average of the two energy average values, one from each position, were used to establish the excess attenuation at the reference position. This excess attenuation value was then subtracted from the excess attenuation values calculated at the other positions to establish the analytic excess attenuation that could be compared with the measured values.

Calculations were made for several assumptions as to the surface between the source and reference microphones. Figure [illegible] shows the maximum attenuation typically observed in the vicinity of [illegible] Hz [illegible] shown in previous figures, plotted as a function of distance for the [illegible] model and for the experimental results. The three calculated curves are for three different assumptions as to the impedance of the surface between the source and reference microphone positions: grassland for both reference positions and microphones, concrete for three of the four microphone positions, and grass for three microphone positions and concrete for one position. All curves assume no atmospheric turbulence. You will note that the calculated curves have similar slopes; their slopes compare well with the experimental curve out to about [illegible]. At greater distances the experimental curve diverges, [illegible] reflecting the influence of turbulence [illegible]

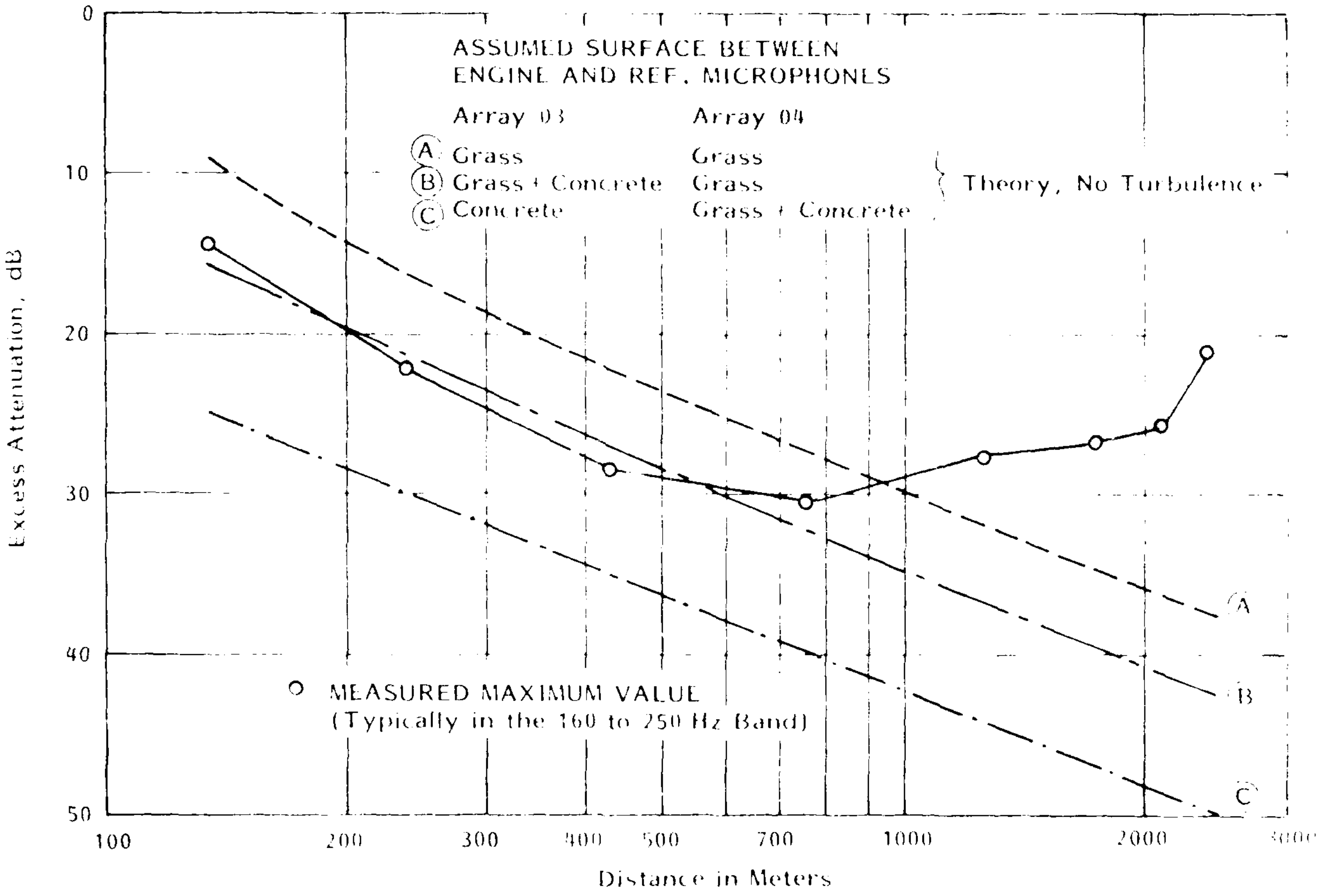

FIGURE 29. MAXIMUM ATTENUATION VALUES GRASS SURFACE, ZERO WIND COMPONENT AND TEMPERATURE GRADIENT

in the atmosphere, [illegible]. The [illegible] curve which assumes grass cover for three microphones and [illegible] for the microphone fits the experimental data well, hence these surface assumptions between the source and reference positions were used in all further calculations.

5.3.2 Turbulent Atmosphere Effects

As noted above, the calculated excess attenuation curves assuming a uniform non-fluctuating atmosphere provide a reasonable fit to the experimental data out to distances of about [illegible] m.* At larger distances the maximum excess attenuation experimentally observed is less than the model predictions, as indicated in Figure [illegible]. In addition, the experimental values as a function of frequency become less broad than the theoretical curves, and show progressively much less attenuation at higher frequencies. Daigle's model introduces adjustments for the turbulent effects of the atmosphere by means of a fluctuating index of refraction and values for the covariance of the amplitude and phase of the spherical waves. The atmospheric effects introduced by this model have little impact on the excess attenuation values at small distances but show increasing influence as distance is increased. The model reduces the excess attenuation beginning approximately in the vicinity of the maximum excess attenuation and at higher frequencies.

Figures [illegible] A and B compare the maximum attenuations as a function of distance for the model, with and without turbulent effects introduced. The figures also shows the experimental values for both grass and snow-cover. The values for the

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*The choice of flow resistance determines the frequency of maximum excess attenuation. However the maximum values and general curve shape as a function of frequency are relatively insensitive to the choice of the flow resistance values.

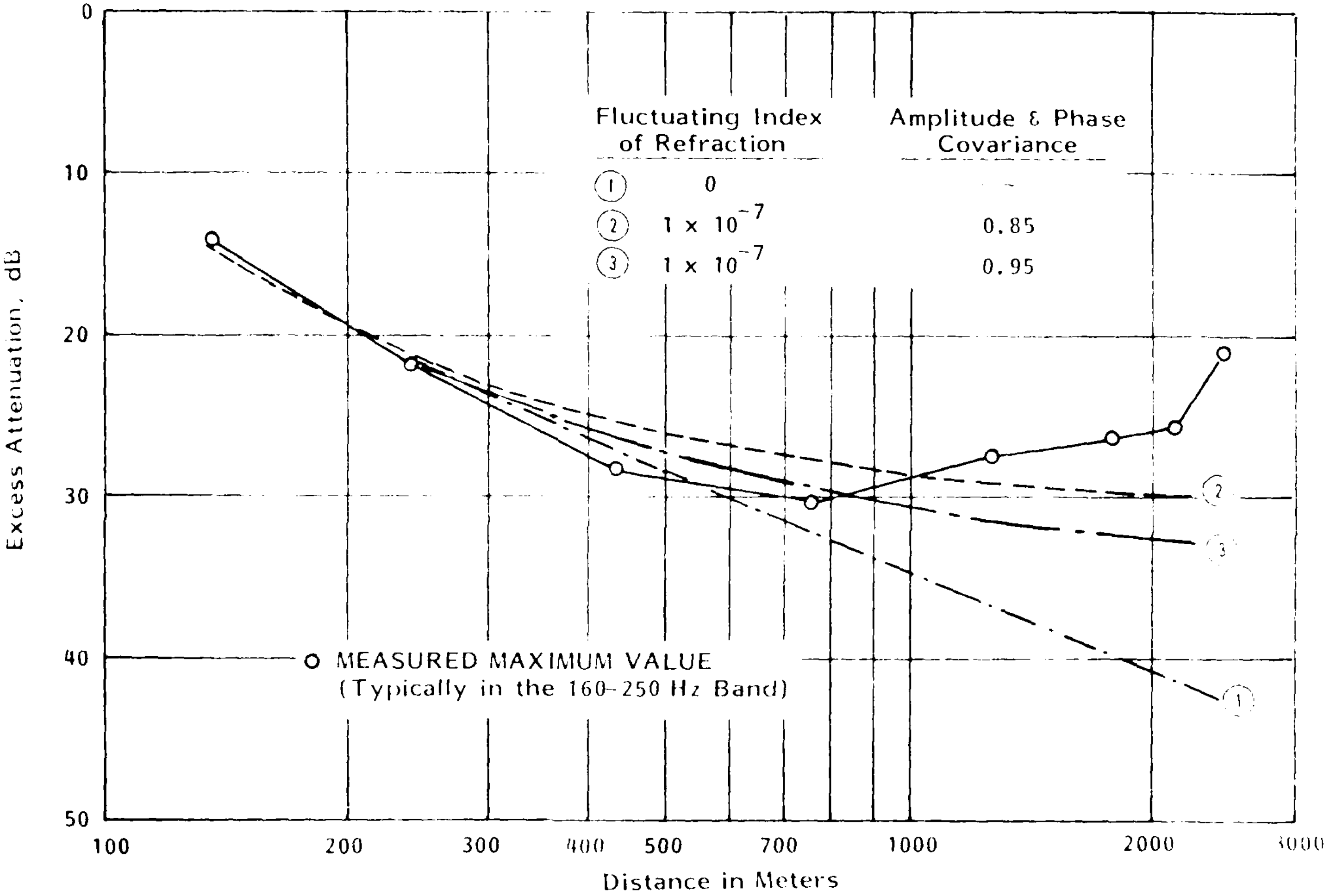

FIGURE 30 A. MAXIMUM ATTENUATION VALUES GRASS SURFACE, ZERO WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT

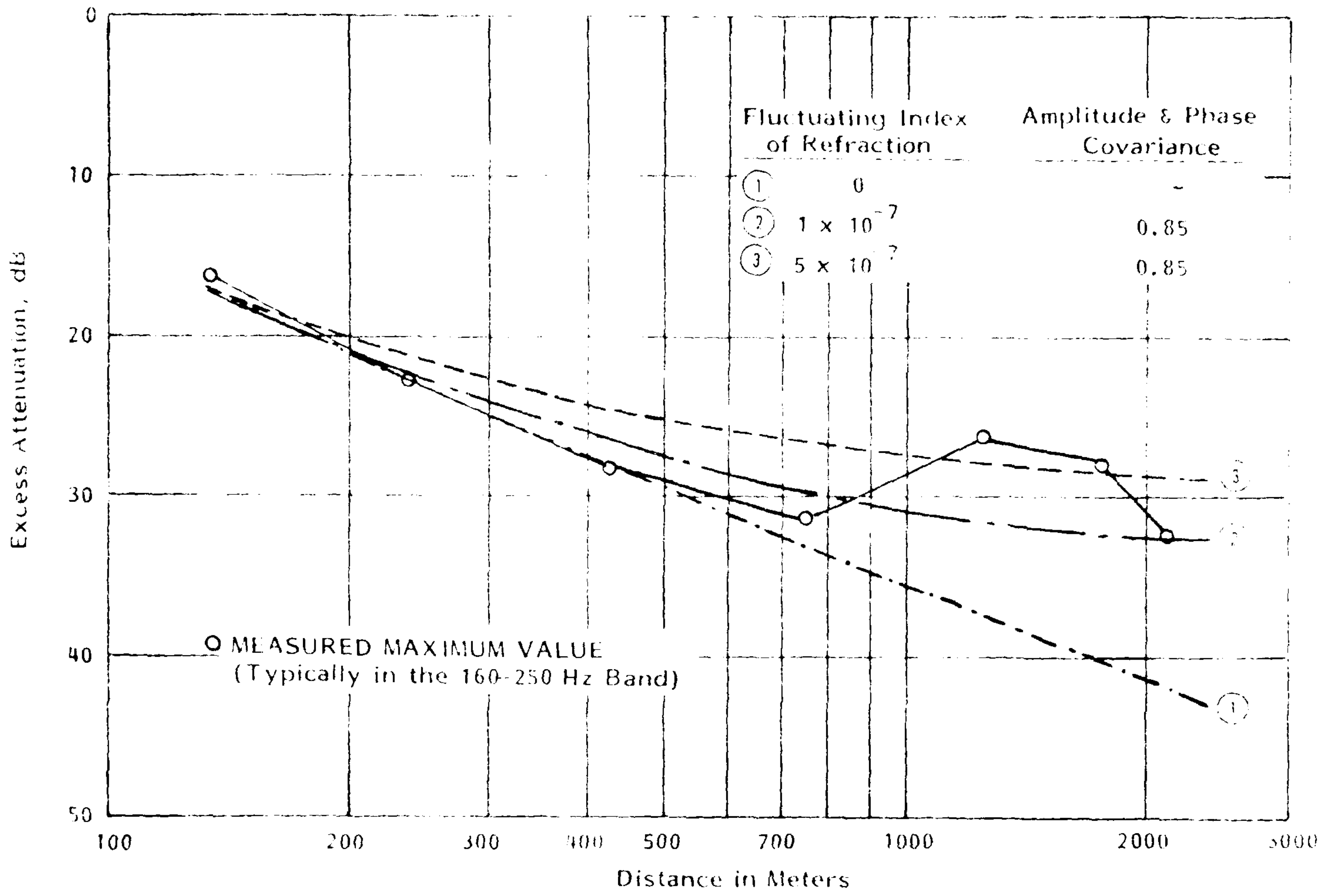

FIGURE 30 E. MAXIMUM ATTENUATION VALUES SNOW SURFACE, ZERO WIND COMPONENT AND NEUTRAL TEMPERATURE GRADIENT

refraction index and covariance are arbitrary. Other combinations of values could yield essentially the same impact on the calculated maximum attenuation values. You will note from the figures that the calculated curves with appropriate choice of parameters now shows a much better fit with the experimental values at the larger distances.

5.3.3 Comparisons for Grass and Snow Cover

Figure 31 compares the measured excess attenuation with grass cover with model predictions at six distances from 134 meters to 2377 meters. Values of the flow resistance and turbulence parameters have been selected to provide a best fit; these values are indicated in the figure. The impedance values have been selected to provide a best fit to the experimental values in the frequency range below the maximum excess attenuation. The turbulence parameters have been selected to provide a fit in the vicinity of the maximum attenuation and at higher frequencies. At the closer distances (134 to 431 m) you will note a relatively good fit between experiment and calculations with little influence from the atmospheric turbulence corrections. At larger distances the atmospheric corrections are substantial.

As indicated in Figure 31, to provide a good fit to the data the flow resistivity value must be increased with distance, generally increasing from the value of 100 cgs rayls at the shortest distances out to 200 cgs rayls at the largest distance. Thus, while a close fit to field results can be obtained at any one distance, the same parameters will not provide an equally good fit at all other distances. The reasons for this can only be speculated upon--perhaps they are related to the extremely small grazing angles involved and the impedance assumptions involved in the model; differences may also be due to the fact that the ground was not perfectly flat as assumed in the theory.

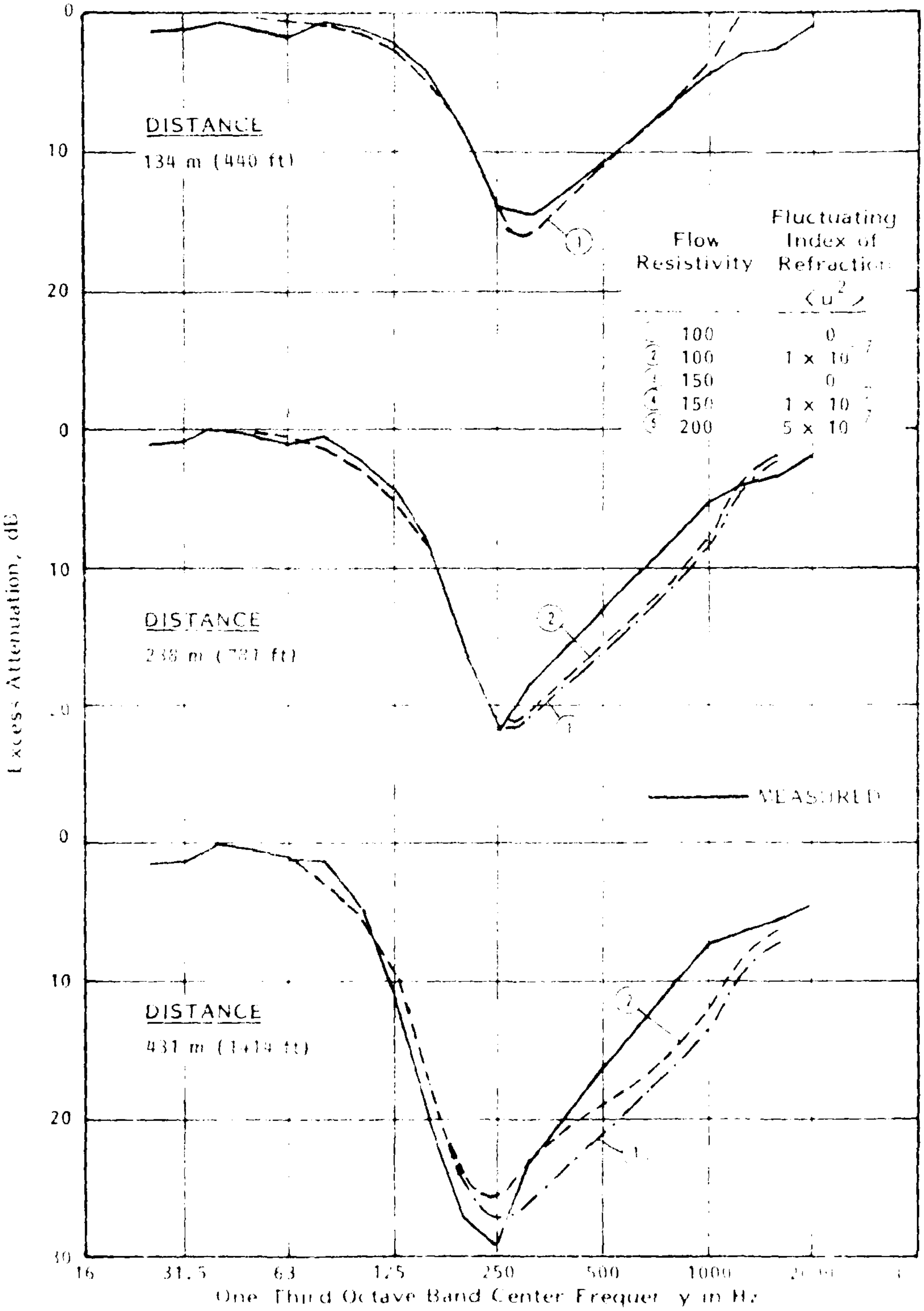

FIGURE 31-5. COMPARISON OF MEASURED EXCESS ATTENUATION WITH ANALYTIC MODEL PROJECTIONS — GRASS SURFACE

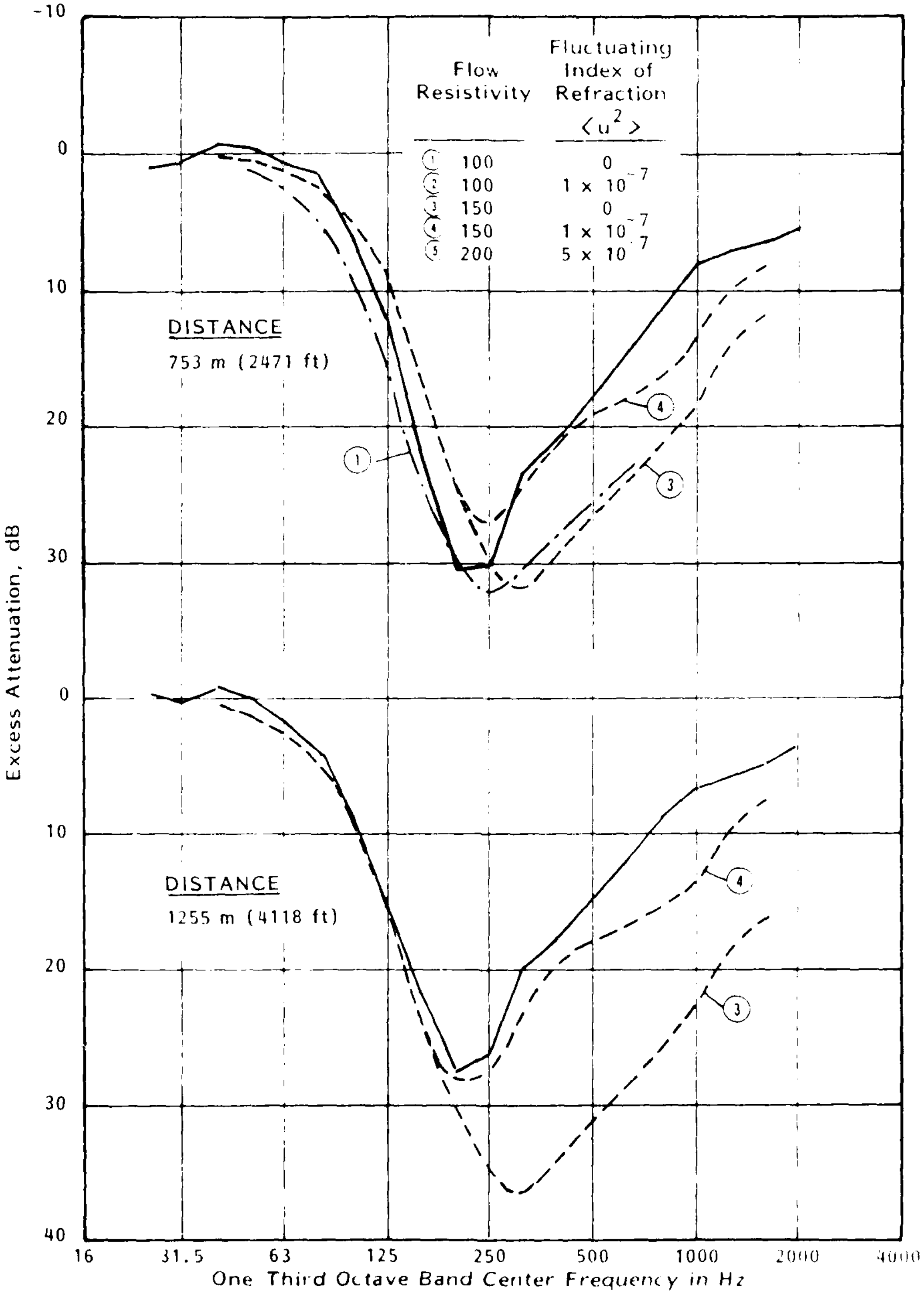

FIGURE 31 B. COMPARISON OF MEASURED EXCESS ATTENUATION WITH ANALYTIC MODEL PROJECTIONS GRASS SURFACE

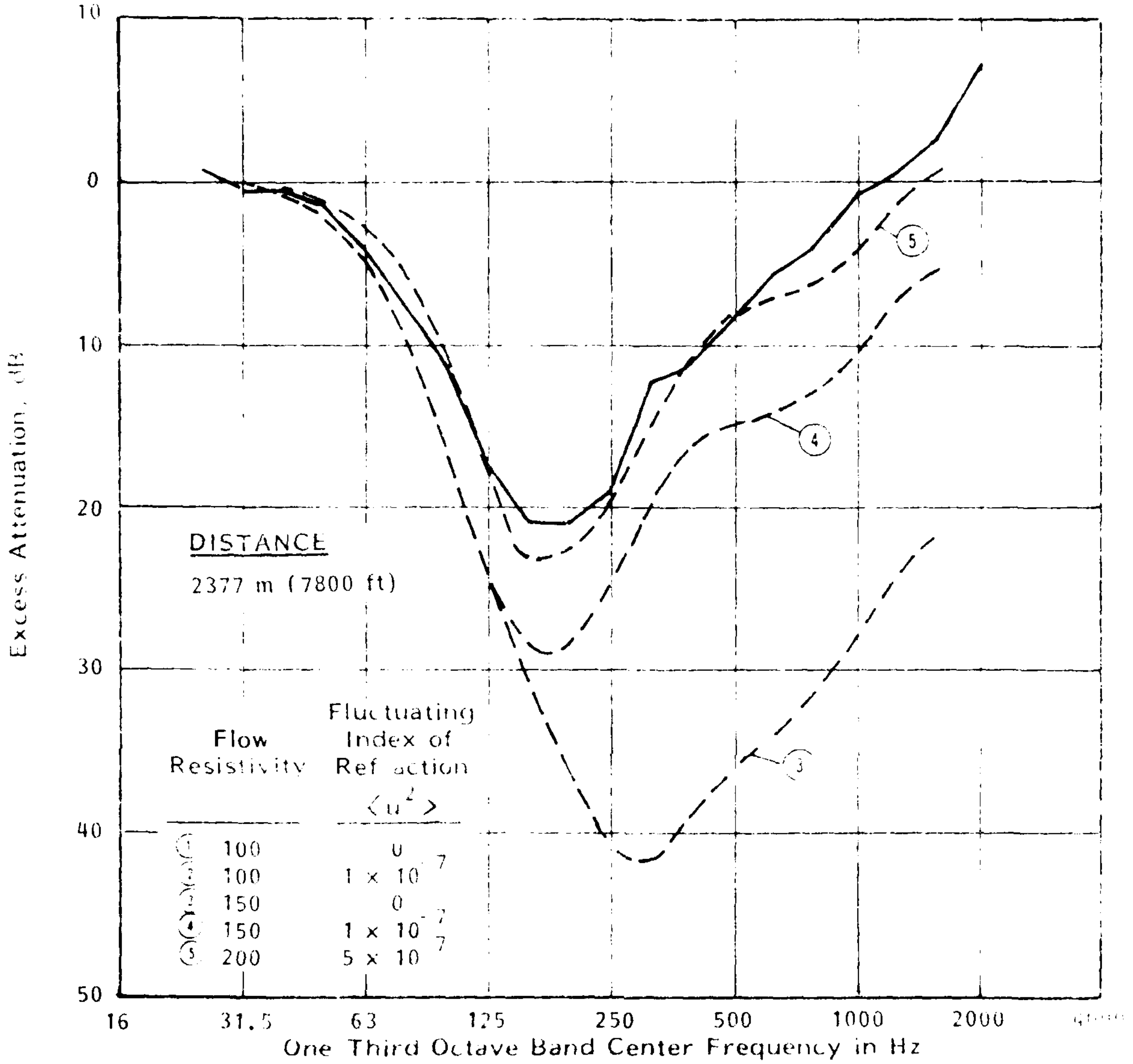

FIGURE 31 C. COMPARISON OF MEASURED EXCESS ATTENUATION WITH ANALYTIC MODEL PROJECTIONS GRASS SURFACE

Figure 32 shows a similar comparison of experimental results with model calculations for the snow cover. For these data, the fit between model and calculations at the shorter distances is not as good as the grass cover situation and reflects the fact that the experimental curves with the snow cover exhibited a narrower frequency band of high attenuation values. You will note that, again, the turbulent atmospheric corrections at longer distances are substantial and materially improve the fit between the model and the experimental data. And, as in the case of the grass cover, the assumed flow resistance values must be increased with distance to obtain a satisfactory fit with the data.

The flow resistivity values used in fitting the data, shown in Figures 31 and 32 are listed below in comparison with results from other studies (Reference 14).

	Flow Resistivity, cgs Units	
	Current Study	Other Studies
Grass Cover	100 to 200	150 to 300
Snow Cover	20 to 50	10 to 50.

The flow resistivity values for the current study overlap or fit within the ranges reported from other studies. For grass cover, the current study values range within or below the values from other studies. The reasons for these relatively low values are not understood. However, it should be noted that the assumptions as to the excess attenuation occurring between the source and the reference microphones influences the shape of the curves for the excess attenuation between reference position and far field positions, thus influencing the choice of the flow resistance that provides the best match between theory and field observations.

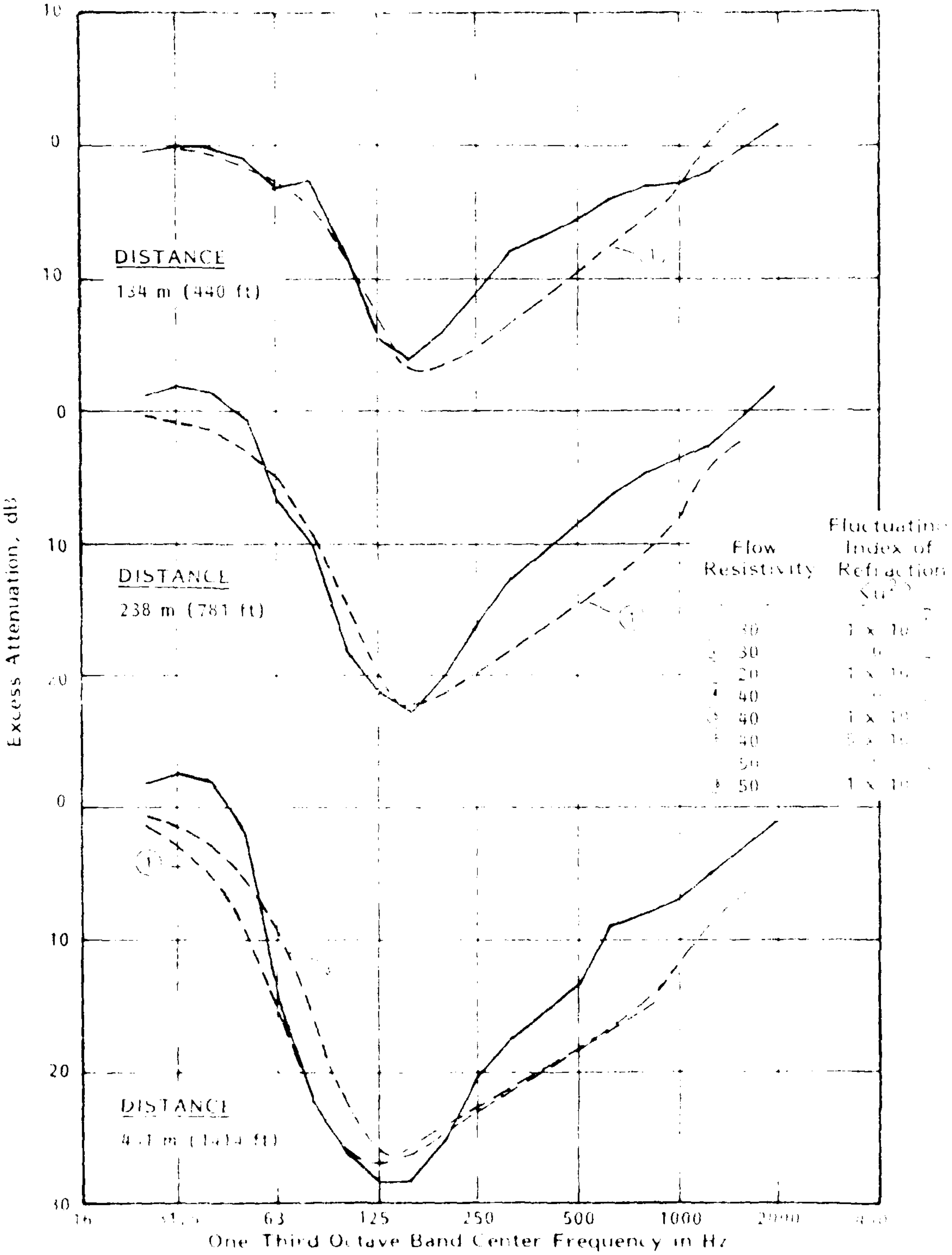

FIGURE 32 A. COMPARISON OF MEASURED EXCESS ATTENUATION WITH ANALYTIC MODEL PROJECTIONS   SNOW SURFACE

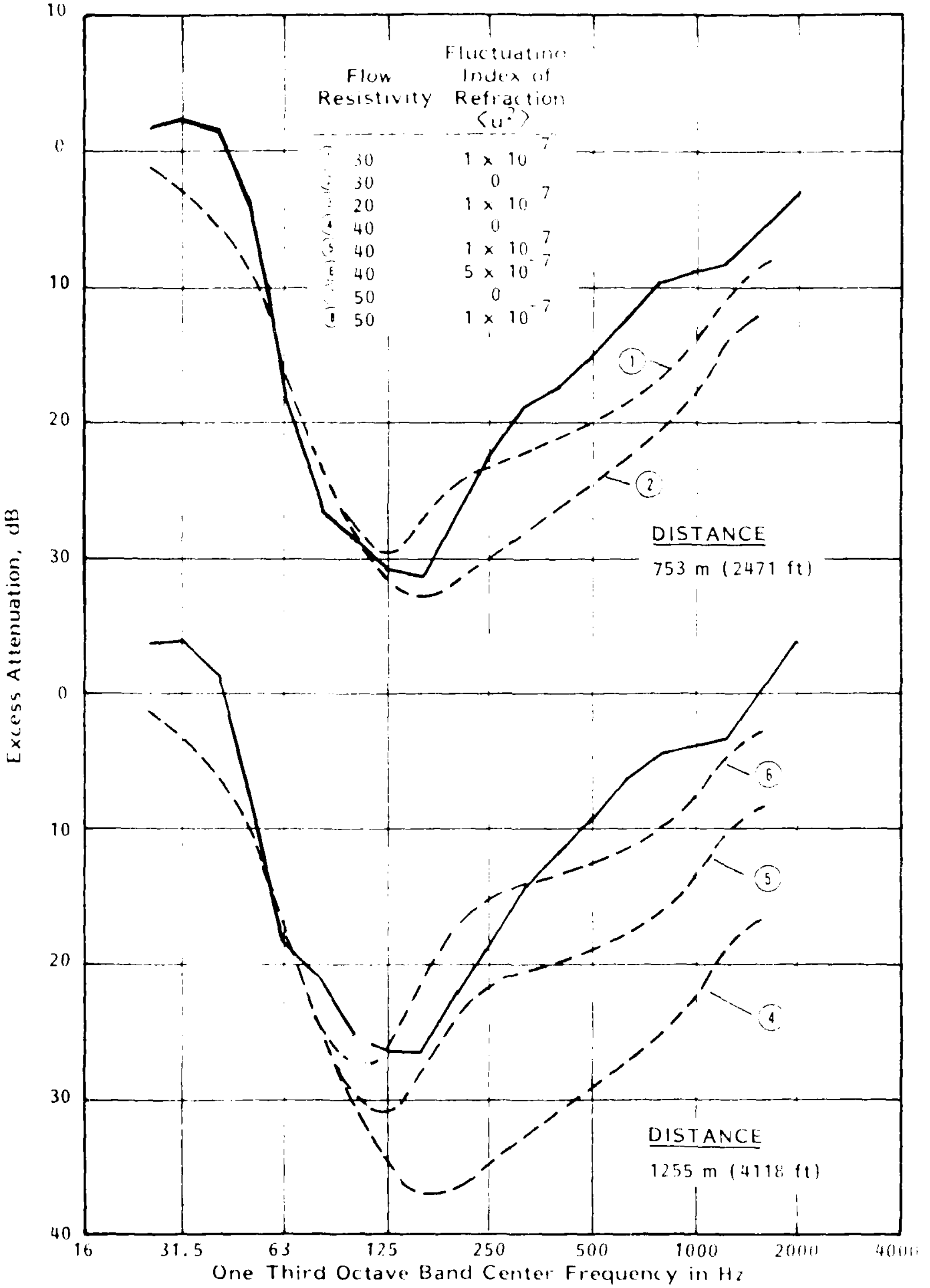

FIGURE 32 B. COMPARISON OF MEASURED EXCESS ATTENUATION WITH ANALYTIC MODEL PROJECTIONS SNOW SURFACE

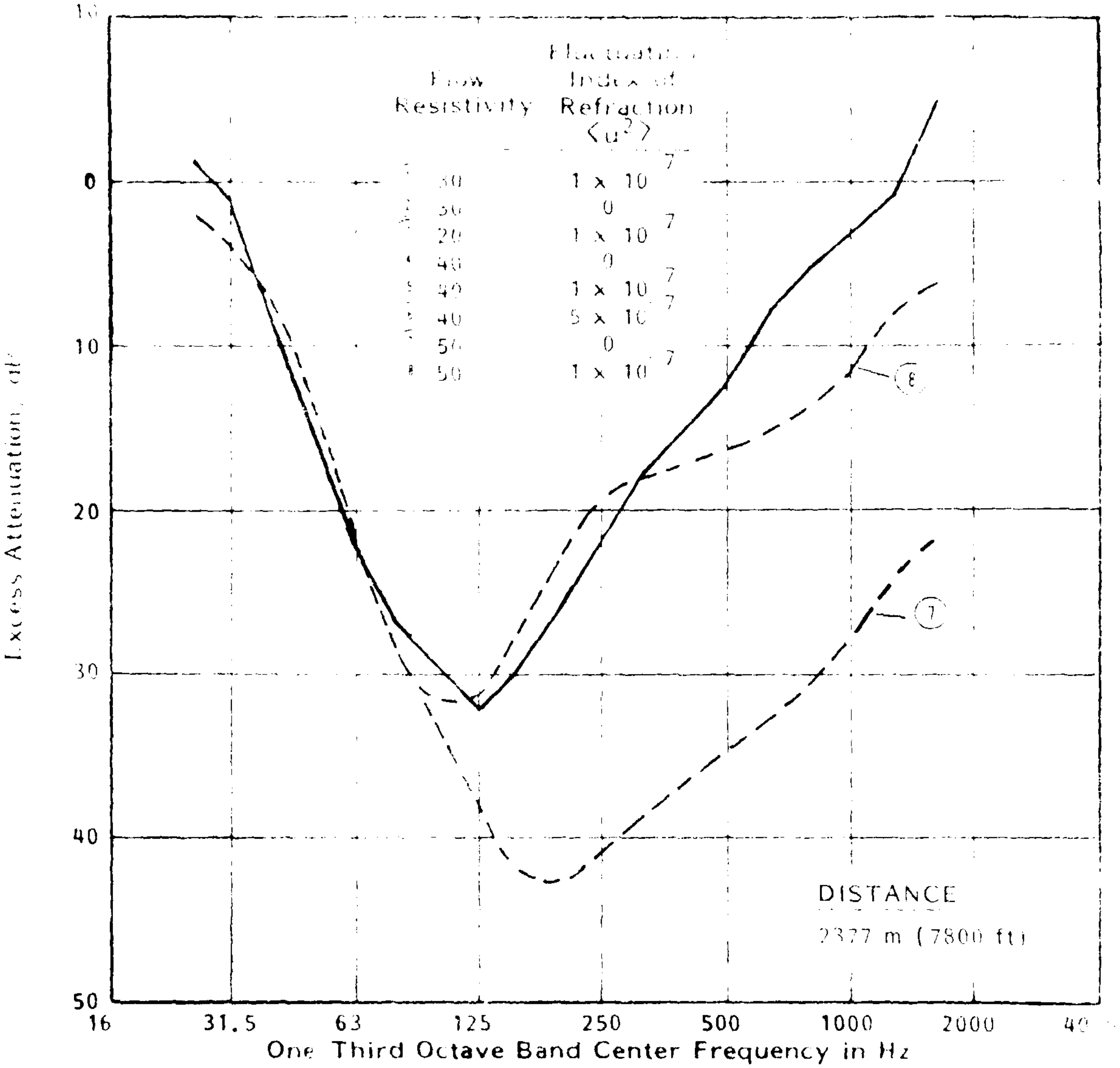

FIGURE 32 C. COMPARISON OF MEASURED EXCESS ATTENUATION WITH ANALYTIC MODEL PROJECTIONS - SNOW SURFACE

6.0 SUMMARY

The excess attenuation data discussed in this report comprises 421 sets of acoustical and metereological data acquired over a 15-month period. Noise from jet engines installed in C-135 and C-141 aircraft were measured at nine or ten monitors at distances ranging from 66 to 2377 m from the source. Measurements were made in opposite directions along a line over near-level terrain which was either grass or snow-covered. Our review and analyses indicate:

1. As expected from previous studies, the ESA data (analyzed in one-third octave frequency bands from 25 to 10,000 Hz, as well as in terms of the overall and A-levels) show large variability. For example, the range of ESA values over the whole set of 421 measurements ranges from the order of 14 dB at short distances and low frequencies upwards to the range of over 50 dB at higher frequencies and distances. The range in which 50 percent of the data is concentrated typically increases with distance and with frequency to maximum values of the order of 12 to 16 dB. Typically, the range increases with frequency up to about 1000 Hz with the range decreasing slightly at higher frequencies, largely due to the loss of data at the higher frequencies. Short-term variations in the ESA values are, of course, much smaller. Analysis of one set of measurements taken over a 90-minute period showed standard deviations which generally increased with distance and with frequency leveling off to the order of 3 to 5 dB at 1000 meter and greater distances.

2. A noticeable characteristic of the frequency variation in excess attenuation data is the maximum which typically occurs in the frequency range between 160 to 250 Hz. This is the so-called ground effect, due to the finite ground impedance. Such a maximum is evident in all data except under extreme conditions of high

negative wind [illegible] [illegible] [illegible] temperature [illegible] [illegible] condi-tions which lead to high values of excess attenuation at frequencies above the [illegible] Hz frequency range.

4. Multiple linear regression analyses show low to moderately high correlation of excess attenuation data with several meteorological and ground surface conditions: the wind component in the direction of sound propagation, the temperature gradient, and the ground surface (grass or snow). The variance accounted for (r^2 values) by these three variables show generally two distinct maxima as a function of frequency. One maximum occurs at low frequencies, [illegible] Hz at the closest distance shifting to [illegible] Hz at the greatest distance; the second high-frequency maximum occurs at [illegible] Hz at [illegible], decreasing to [illegible] Hz at the greatest distances. The r^2 values in the vicinity of the lower frequency maxima are on the order of 0.5 to [illegible], and for the second maxima, [illegible] to [illegible], with values generally increasing with distance. The r^2 values are typically very low in the vicinity of [illegible] Hz where the [illegible] excess attenuation values occur. The most significant of the three variables is the ground [illegible] at low frequencies and, at the higher frequencies, the most significant variable is the wind component.

Further analysis indicates that the variance accounted for can be modestly improved at medium and higher frequencies by introducing the wind component as squared and cubed variables to account for the fact that the variation of EXA with wind component values is not linear. [illegible] test condition, the direction of array, was found to be significant since the addition of the array direction as [illegible] variable [illegible] in a modest [illegible] increase in the variance accounted for, typically in the higher frequencies, most notably at [illegible] Hz. This influence due to array direction is believed to be [illegible] due to the differences in ground surface between the [illegible] phase reference positions between the two array directions.

4. The influence of ground surface conditions is most easily identified under zero wind component and neutral temperature conditions. For these conditions, the maximum excess attenuation for grass cover varies from 315 Hz at the closest distance, decreasing to 200 Hz at the greatest distance. The maximum with snow cover occurs at lower frequencies, ranging from 160 Hz at the shortest distance to 125 Hz at the greatest distance. Thus, with snow cover, there is greater excess attenuation at frequencies below 160 Hz, but less attenuation, compared to grass, above about 250 Hz. Comparison of the ESA curves with theoretical calculations show reasonable fit assuming surface flow resistivity values of 100 to 200 cgs rayls for grass and 20 to 50 cgs units for snow. These resistivity values range within or slightly below the values reported from other studies.

5. The extent of changes in ESA values with changes in wind component or temperature gradient varies considerably with frequency and distance. Typically, ESA values are more sensitive to wind component changes than to temperature gradient changes. There is generally a moderate effect of either wind component or temperature gradient on ESA values at low frequencies and small effect of these variables in the frequency range from 125 to 300 Hz. In the low frequency range (typically 25 to 100 Hz) attenuation values generally show well-ordered increases with decreasing wind component and temperature gradient values. In the frequency range above about 300 Hz, ESA sensitivity to wind component and temperature gradient increases with generally a greater range of change with negative values of wind component or temperature gradient values than for positive values.

6. Comparisons with the earlier work of Parkin and Scholes in Great Britain, which also involved measurements of jet engine noise over level grassland, show consistent similarity in trends of excess attenuation data. However, the maxima observed for the current results occur at lower frequencies than found for the

[illegible] measurements. This may be due to [illegible] flow resistivity of the grass cover in the current measurements compared to the Parkin and Scholes measurements [illegible]. There is agreement in the measured changes in attenuation values with wind component between the current study and the Parkin and Scholes measurements.

7. Comparison with the limited field airport community measurements which formed the basis for the present NOISEMAP excess attenuation algorithms show major differences in EA values. The earlier measurements show much greater attenuation at frequencies of 125 Hz and lower. Some of these differences may be due to the fact that, unlike the current measurements, the earlier measurements were made at sites where there were many intervening objects, and nonuniform surface conditions, between the airplane reference and distant field measurement locations.

8. Excess attenuations for conditions of near-zero wind component and neutral temperature gradient were compared with theoretical predictions based on a spherical radiation from a point source located above a flat surface. The model assumes the surface is locally reactive, with a surface impedance characterized by an effective flow resistance value. Atmospheric turbulence effects were also incorporated in the model. Different surface impedance and atmospheric turbulence quantities were assumed on a trial and error basis to obtain a best fit between the study results and predictions. In general, the model predictions fit the experimental results quite well, if one allows for a moderate increase in the flow resistivity with distance. Introduction of turbulent atmospheric adjustments greatly improves the fit between experiment and model calculations at distances beyond about [illegible] meters.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The ultimate goals of the work described in this report are improved procedures and data for calculating the "average" noise environment in the vicinity of airports. The conclusions and recommendations given below are directed towards the NOISEMAP computer program which is used by the Air Force and the Department of Defense to develop airbase noise contours. Conclusions and recommendations for any changes in the excess attenuation model and algorithms incorporated in the NOISEMAP program are discussed separately in Reference 2.

Contours generated by NOISEMAP are usually intended to depict the noise environment in the vicinity of an airbase based upon "typical" or "average" conditions existing over a period of time, usually average annual conditions. To this end, it is desirable to use air absorption and excess attenuation values that are representative of average conditions at the particular airbase. Where it is difficult to determine average conditions over a year, or where there are large seasonal differences, the intent is to select conditions that are representative during the time of year that people are likely to be most sensitive to noise (summer rather than winter conditions, for example).

As an example, the air absorption values used in calculating the noise level versus distance curves are based upon specified temperature and humidity conditions. Many noise contours for civil airfields are based upon "standard day" conditions (temperature 59°F and relative humidity of 70%). Analysis has shown that the contours based on these conditions are usually quite representative of conditions at many airfields (civil and military) except for low temperature conditions (Reference 15). However, current NOISEMAP procedures call for selecting representative airbase temperature and humidity values in calculating noise level versus distance curves for each airbase. These values are based upon considering the average absorption coefficient for each month during the year at the airbase and taking the conditions representing the sixth lowest average absoption coefficient.

The current measurements confirm previous measurements (References 3, 4, 5, 8) and theory and make it very clear that the actual excess attenuation at a site varies significantly with meteorological conditions, surface cover, and other factors. Considering prevailing wind conditions and the variations in terrain that exist around any airbase, it is clear that average excess attenuation values, when accurately determined, will vary from point to point and will vary with respect to the source location. It will probably never be practicable, nor desirable, to determine sets of average excess attenuation values for each different grid location in computing contours.*

For typical NOISEMAP applications it is desirable to use excess attenuation values that are related to some meaningful average of local conditions at each base. In general this average should be somewhat on the conservative side, based on downwind conditions, for example, rather than upwind. These curves could be based upon either: (a) as recommended for the current model, a standard set of curves used uniformly from airbase to airbase, or (b) a set of curves representing an average which is tailored to some average of meteorological and terrain conditions for the specific airbase. In this case, the averages should be derived from geographic and terrain features that can be clearly identified and calculated from available data or records.

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*It may well be desirable to develop a detailed prediction program that can accurately calculate excess attenuation for any given set of circumstances and terrain and meteorological conditions. The program can be helpful in providing detailed predictions for a given source-receiver situation.

Towards achieving the goal expressed above, the current measurements show the following:

1. A sizeable percentage of the large variations in measured ESA data can be explained in terms of dependence on observed meteorological and ground surface conditions. However, a sizeable residual of the variability cannot be correlated with measured factors. This residual is due, in part, to experimental errors, but is also due to other physical factors that are not currently measured or taken into account. It is logical to expect that for other sites, similarly large variations in excess attenuation would occur and that although much may be explained by correlations with meteorological and surface conditions, there is likely to be a sizeable residual leading to variations in excess attenuation that are due to factors not yet adequately accounted for.

2. There is good agreement in the variation of excess attenuation with wind component between the current measurements and the Parkin and Scholes studies. This agreement indicates that the current data base provides a reasonable basis for estimating changes in excess attenuation with changes in wind component values. It is also likely, although not confirmed, that the current data base provides a reasonable basis for estimating changes in ESA with changes in temperature gradients.

3. The good fit with current theoretical calculations (after allowing for introduction of empirical constants for atmospheric turbulence), observed even to large distances, suggests that theory can be used with considerable reliance in predicting excess attenuation over near level terrain having near uniform ground surface conditions where ground impedance values can be characterized by a single set of numbers. This suggests that where-

[illegible] attenuation for [illegible] wind and near neutral temperature [illegible] the [illegible] for [illegible] field measurements [illegible]

4. There are [illegible] differences between [illegible] experiment measurements and [illegible] frequencies [illegible] differences.

[illegible] measurements [illegible] the aircraft [illegible] frequencies.

[illegible]

[illegible]

1. It is not evident, at this time, if there is adequate "station" meteorological information available to determine meaningful averages for calculating the excess attenuation values for individual airbases. To this end, there is a need to review the kind and quality of the meteorological information that is available from the weather records. Specifically, sets of meteorological summary data for several airbases should be examined to determine whether or not it is possible to specify meaningful average temperature gradient and wind component conditions for individual bases. One potential drawback, for example, is the fact that the available meteorological information may not provide adequate information for estimating low altitude temperature gradient conditions for different times of day and different seasons.

2. Since the ESA values may vary significantly with time of day (being affected by both wind and temperature gradient conditions which typically have daily patterns) it would be well to review the basis to be used for selecting the most representative time of day for calculating average temperature and wind gradient conditions. Selection of the time of day is influenced both by the relative activity at an airbase as a function of time of day and the changing sensitivity of community areas to aircraft noise (increased community sensitivity to noise in evening and nighttime hours, for example).

3. Additional ESA field measurements, similar to those described in this report should be undertaken, although the scope of the measurements may be significantly reduced over what might once have been envisioned because of greater use of theory, utilizing empirical constants, reduces the need for field measurements over surfaces of differing ground impedance. Many, if not most, airport situations involve relatively irregular terrain with obstacles (building, shrubbery, trees, etc.) which clearly block line-of-sight and which may include sections of terrain having

widely different ground impedance. These conditions are ones for which it is particularly difficult to apply theoretical results. Thus it is desirable to extend the ESA measurements to cover terrain of more irregular features involving (a) larger surface irregularities and (b) a wider mixture of terrain surfaces. The general techniques and measurements should be similar to those used at Dayton and the measurements should be conducted over a reasonable range of wind component and temperature gradient conditions. It is expected that there will be relatively large variations in excess attenuation and meterological data such that analysis probably should be in terms of statistical analysis of a relatively large number of measurements.

4. To extend the application of theory in predicting field excess attenuation and to better define any empirical constants that may be needed in applying the theory to real-life situations, it is recommended that a program be undertaken in which individual sets of ESA measurements be taken and compared with theory on a set by set basis. In undertaking these measurements, the meteorological measurements should be extended to provide measurements of atmospheric turbulence existing at the time of measurements (see Reference 16, for example). These measurements could be conducted, if desired, at the Dayton site for selected meteorological conditions. Large numbers of data sets need not be acquired, and the study should emphasize comparisons and reasons for differences between theory and measurements on an individual set basis. The results from this program should result in a better understanding of the extent to which current theory can be used to predict excess attenuation at relatively large distances from the source. It also should result in better selection of empirical constants that may be needed in predicting the effects of atmospheric turbulence on sound propagation in actual field situations.

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APPENDIX A

PROPAGATION OF SOUND NEAR GROUND SURFACES

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PROPAGATION OF SOUND NEAR GROUND SURFACES

The acoustic impedance of the ground surface may be represented by a single parameter, the flow resistivity of the surface layer, when the ground surface is uniform.

Let [illegible] flow resistance unit thickness. In [illegible] R + iX = characteristic impedance of the ground [illegible] expressed [illegible] the impedance [illegible] given by

$$R = \rho c\left[1 + 9.08\left(\frac{f}{\sigma}\right)^{-0.75}\right]$$

$$X = \rho c\left[11.9\left(\frac{f}{\sigma}\right)^{-0.73}\right]$$

where f = [illegible]

[illegible]

Consider a point source [illegible] at a height h_S above the ground and a receiver [illegible] distance R away [illegible] height h_R [illegible] of the reflected wave is given by

$$\tan \psi = \frac{h_S + h_R}{R}$$

Assuming the ground [illegible] in the ground, the plane wave reflection coefficient [illegible] given by

$$R_p = \frac{\sin \psi - (Z_1/Z_2)}{\sin \psi + (Z_1/Z_2)}$$

[illegible]

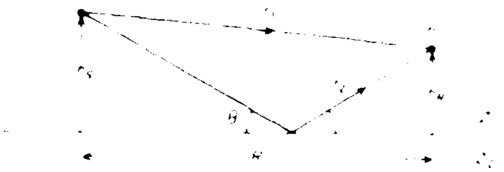

Fig. A1. Sound-receiver geometry for straight-line propagation

Following [3], the velocity potential at the receiver can be approximated by

$$\phi = \frac{e^{ikr_1}}{r_1}\left[1 + \left(\frac{r_1}{r_2}\right)Qe^{ik\Delta r}\right]$$

where

k = propagation coefficient in air = $2\pi f/c_0$

r_1 = path length of direct wave

r_2 = path length of reflected wave

Δr = $r_2 - r_1$ = path length difference

Q = image source strength = $|Q|\,e^{i\phi}$

= $R_p + F(w)(1 - R_p)$

where $F(w)$ is the boundary loss factor or complex "ground wave" function and w is the numerical distance for a locally reacting surface given by

$$w = \frac{ikr_2}{2}\frac{(\sin\theta + Z_1/Z_2)^2}{(1 + \sin\theta\; Z_1/Z_2)}$$

[illegible]

$$(w) \ldots 1^{2}\, w^{2} \ldots \operatorname{erfc}(\ldots w)$$

[illegible]

[illegible]

$$A \ldots \left| 1 + \left(\frac{r}{r}\right) \ldots \right|$$

[illegible]

$$A \ldots \left[1 + \left(\frac{r}{r}\right)^{2} \ldots^{2} + \frac{2r}{r} \ldots \cos\left(\ldots + \ldots \right) \right]$$

[illegible]

[illegible]

$$A \ldots \left[1 + \left(\ldots \right)^{2} \ldots + \ldots (\ldots + \ldots) (\ldots) \right]$$

[illegible]

$$\left[1 + \left(\ldots \right)^{2} \right]^{\frac{1}{2}}$$

and r_j, [illegible], [illegible], and [illegible] are the values corresponding to the respective center frequencies of the one-third octave bands f_j.

An example of the calculations of excess attenuation is shown in Fig. A2 for a source height of 0.27 meter, a receiver height of 0.42 meter, at a distance of 7.62 meters for three values of ground flow resistivity. This example was compared in [5] with measurements over a densely-packed grass field. Slightly different expressions for the reflection coefficient R_j and the numerical distance w were used in [5], but the results are very close to those in Fig. A2, which assumed a locally reacting ground surface.

Effect of Atmospheric Turbulence

The interference spectrum between direct waves and those reflected from the ground is strongly influenced by the fluctuations in phase and amplitude induced by propagation through turbulence. References [illegible] and [illegible] develop a theory for the fluctuations of phase and amplitude of the propagating waves, with only partial correlation between direct and reflected waves. The mean square value of the excess attenuation can be predicted [illegible] and is given by

$$A_e = -10 \log_{10} \left\{ \left[1 + \left(\frac{r_1}{r_2} \right)^2 Q^2 \right] \left[1 + \langle a^2 \rangle \right] + \frac{2r_1}{r_2} Q \cos\left(\frac{2\pi \Delta r}{\lambda} + \theta \right) \left(1 + \rho \langle a^2 \rangle \right) \exp\left[-\sigma^2 (1 - \rho) \right] \right\}$$

where $\langle a^2 \rangle$ = normalized standard deviation of the amplitude of the reflected and direct waves

ρ = partial covariance between the reflected and direct sound (both phase and amplitude)

σ = standard deviation of (wavenumber x path length) of the reflected and direct waves.

[illegible]

[illegible] = effective [illegible]
= [illegible] measurements [illegible]
[illegible]
[illegible] = [illegible]
[illegible] = [illegible]
[illegible]

[illegible]

In the [illegible], the phase and amplitude fluctuations [illegible] can be found from

$$s^2 = \tfrac{1}{2}(I_1 + I_2), \qquad \langle[\log_e(1 + a)]^2\rangle = \tfrac{1}{2}(I_1 - I_2)$$

where

$$I_1 = (\ldots)^{\frac{1}{2}} \ldots$$

$$I_2 = (\ldots)^{\frac{1}{2}} \ldots K^2 \ldots \frac{1}{\ldots(\ldots + 1)\ldots 8}\left(\frac{\ldots}{2}\log_e\frac{1 + \ldots(2\ldots)^{\frac{1}{2}}}{1 - \ldots(2\ldots)^{\frac{1}{2}}} + \arctan\frac{\ldots}{\ldots(2\ldots)^{\frac{1}{2}}} + \arctan\frac{\ldots}{1 + \ldots(2\ldots)^{\frac{1}{2}}}\right)$$

where

$$\ldots = (1 + 1/\ldots^2)^{\frac{1}{2}} - 1$$

[illegible]

The expression $\langle a^2 \rangle$ can be obtained from x = [illegible] using the numerical approximation

$$\langle a^2 \rangle \doteq \begin{cases} \dfrac{x}{1 + (11/4)x} & x \leq 1, \\ 0.27x^{0.33} & x > 1. \end{cases}$$

The covariance of the amplitude and phase fluctuations, [illegible], can be derived from

$$[illegible] = \frac{\Phi(\ell/L)}{\ell/L}$$

where

$$\Phi(\ell/L) = \int_0^{\ell/L} \exp(-u^2)\,du$$

$$= \frac{\sqrt{\pi}}{2} \operatorname{erf}\left(\frac{\ell}{L}\right)$$

$$\ell = \tfrac{1}{2}(\text{maximum path separation})$$

$$= \frac{h_R h_S}{h_R + h_S}$$

and L = effective scale of turbulence

An example including the effects of turbulence is shown in Fig. A3 for a source height of 1.8 meters and a receiver height of 1.5 meters at a distance of 200 meters. The ground flow resistivity was taken to be 300 cgs units, and the covariance was 0.80, while the value of $\langle \mu^2 \rangle$, the fluctuating acoustical index of refraction, was varied. This example was shown in [7] again using slightly different expressions for the reflection coefficient R_p and the numerical distance w. The results shown in Fig. A3 are within 1/2 dB of those shown in [7].

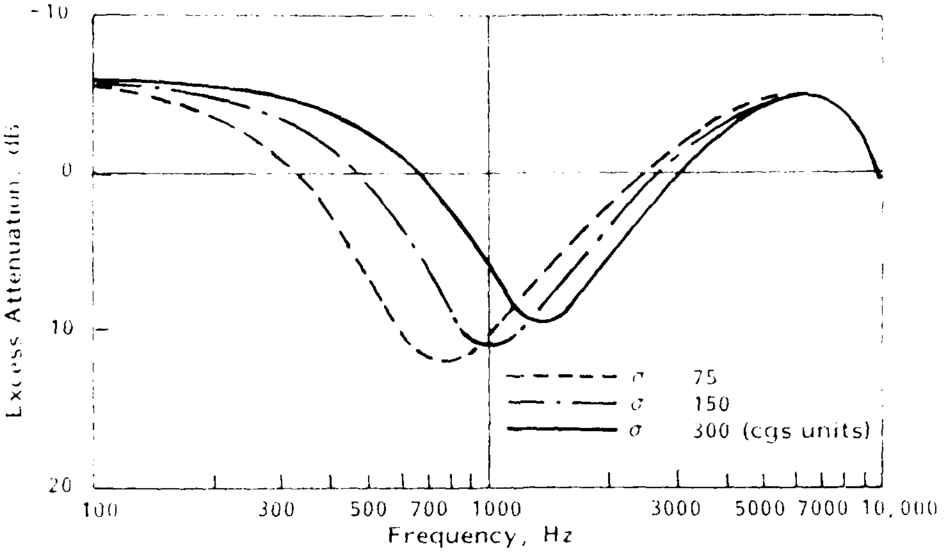

FIGURE A2. EXCESS ATTENUATION FOR SOURCE AND RECEIVER HEIGHTS 0.27 AND 0.42 m ABOVE GROUND, AT DISTANCE OF 7.62 m, WITH NO ATMOSPHERIC TURBULENCE

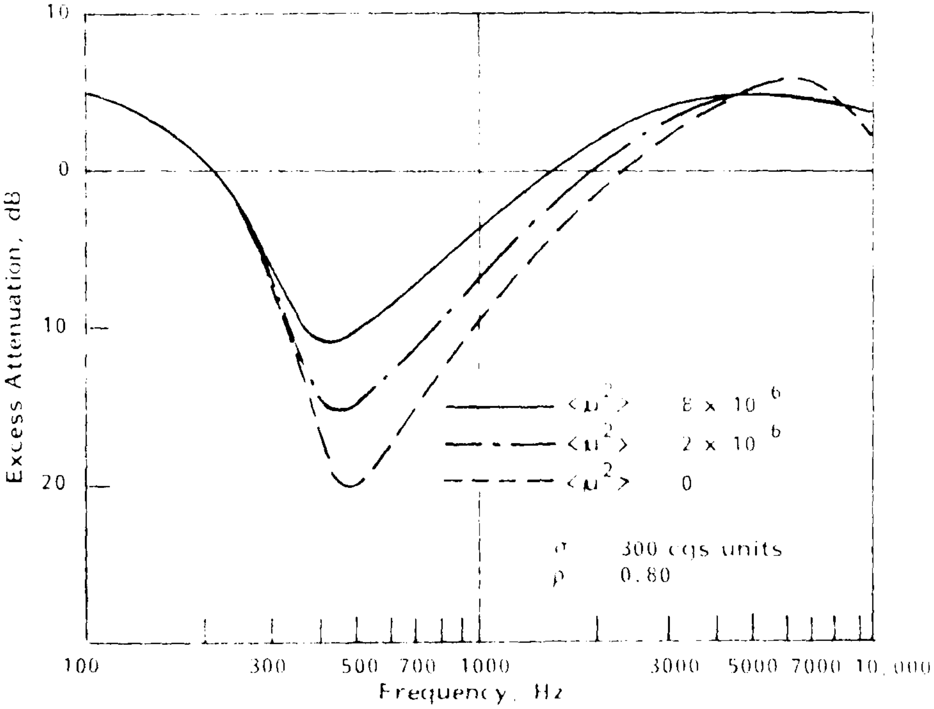

FIGURE A3. EXCESS ATTENUATION FOR SOURCE AND RECEIVER HEIGHTS 1.8 m AND 1.5 m ABOVE GROUND, AT DISTANCE OF 200 m WITH ATMOSPHERIC TURBULENCE

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